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1 Introduction

Pumps are now widely used in irrigation systems and schemes. When there is a pump in an irrigation system or scheme, the running costs rise dramatically and the most economical pump that is technically suited to the application must be selected. This Chapter contains information that includes a description of pumps generally used in irrigation as published in the Chapter on pumps in the **Irrigation Design Manual** of the ARC-institute for Agricultural Engineering, as well as practical information on the choice, installation, evaluation, operation and maintenance of pumps.

Most pumps are able to pump most liquids, with or without solids in suspension, but in this chapter we will only be looking at the pumping of relatively clean water at more or less ambient temperature.

The function of a pump in any hydraulic system is to add energy to the system. Figure 6.1 clearly shows that without a pump it would be impossible for the water to flow from point A to point B. If a pump should, however, be added to the hydraulic system between points A and B, as indicated in Figure 6.1, and sufficient energy is added to the system, the water will flow from point A to point B.

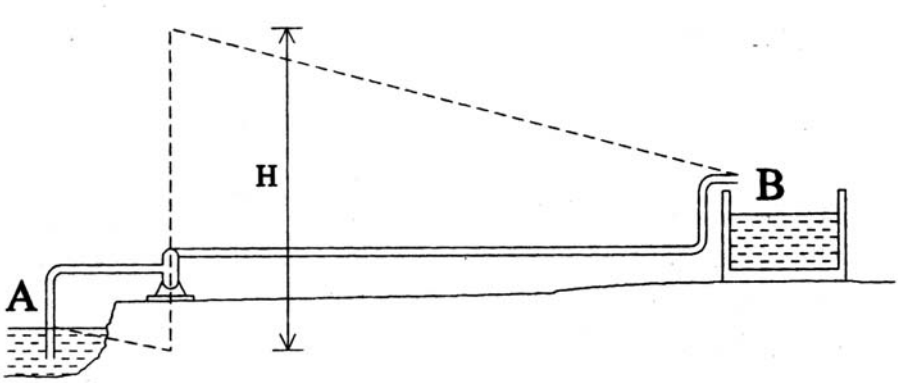

Figure 6.1: Addition of energy to a hydraulic system

The amount of energy added to the hydraulic system in the form of pressure head will determine the slope of the hydraulic gradient, which in turn will determine the flow therein. In Figure 6.1, the total energy added to the hydraulic system by the pump is represented by H and the hydraulic gradient by the dotted line.

A pump is included in a hydraulic system for the purpose of adding sufficient energy to the system. This energy, which is supplied in the form of pressure head, must equal the static head, emitter pressure (for e.g. in overhead irrigation systems) and friction and other losses to have the desired effect.

The energy that is added to a hydraulic system in the form of pressure head is dependent on the flow in the system. However, a balance should be maintained between the pump head and the pump delivery on the one hand and the energy that has been added to the hydraulic system and the flow therein on the other.

2 Classification of pumps

Figure 6.2 displays a simplified classification of pumps for irrigation. Most centrifugal pumps are commonly used for irrigation, but as far as the positive displacement pumps are concerned, it is only the progressive cavity rotary type pumps that are sometimes used for irrigation. The latter entails a spiral shaped rotor and horizontal and vertical types are being marketed in the RSA. These types of pumps, which can very well be commonly used for irrigation, are discussed in Section 2.1 and 2.2. Positive displacement pumps are generally used for the dosing of chemicals and this is discussed in Section 2.3.

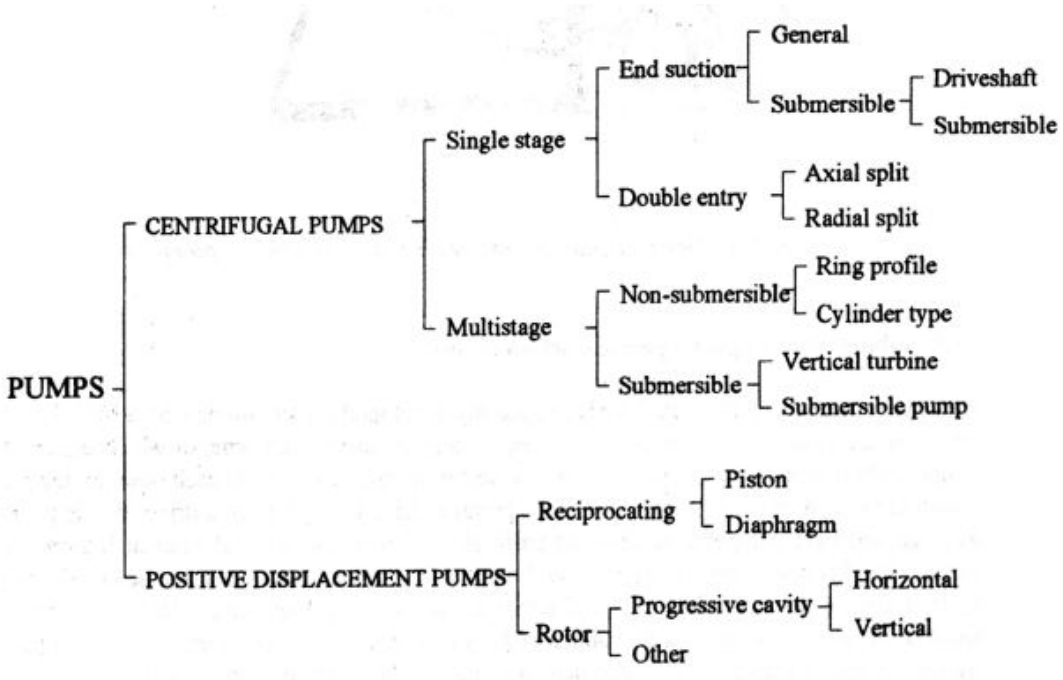

Figure 6.2:Classification of pumps for irrigation

2.1 Centrifugal pumps for irrigation

Centrifugal pumps are widely used for irrigation. The most common types will be discussed.

2.1.1 General single stage end-suction pumps

This is the pump most commonly used for irrigation. It is the most basic centrifugal pump and all the other types of centrifugal pumps have been developed from this one to satisfy certain specific requirements. These types of pumps are usually equipped with radial-flow impellers, but mixed-flow impellers are also used for pumps with larger pump deliveries against smaller pump heads. One of the different types of volute casings is usually used.

The main reason why there is a moving away from these types of pumps is NPSH (nett positive suction head) problems. Parallel and series couplings are also commonly found with these types of pumps. (See Section 3).

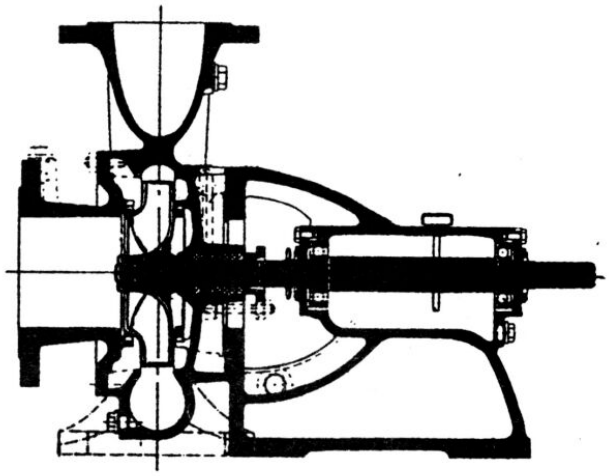

Figure 6.3: General end-suction single stage centrifugal pump

2.1.2 Submersible single stage end-suction pumps

These types of centrifugal pumps have been specially developed for situations where NPSH problems are being experienced. The two basic types, namely the drive shaft type, of which the axial-flow pumps are best known, and drainage pumps can best be distinguished from each other by the position of their drivers. With the axial-flow pump, the pump is driven by means of a driver that is positioned above ground and the impeller by means of a drive shaft. The pump is installed in such a way that the impeller itself is below the water level and the pump thus has a positive suction head. The impeller itself is also of the axial-flow type and thus the name axial-flow pump. However, mixed-flow impellers are also sometimes used. Tubular shaped casings are used for these types of pumps. They are usually applied where large pump deliveries have to be pumped against small pump heads.

These types of pumps, however, also show up as multistage pumps and they are sometimes equipped with mixed-flow impellers.

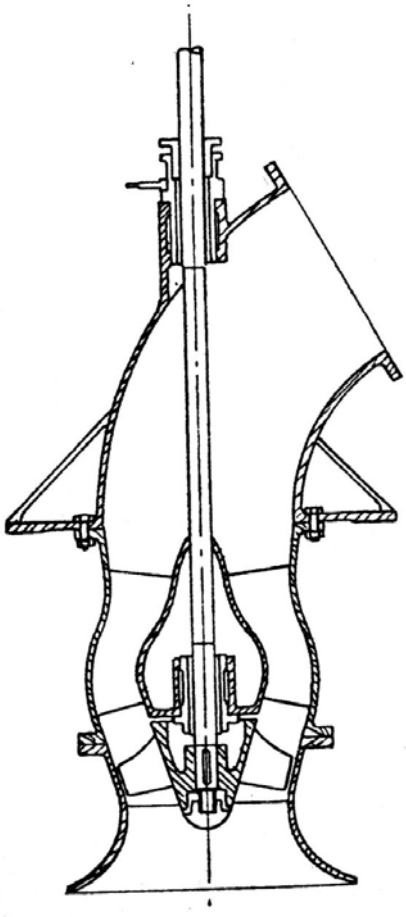

Figure 6.4: Axial flow pump

The electric motor of the other type, which is known in the trade as a drainage or fountain pump, together with the pump, forms a unit. The whole unit can be installed below the water level because the motor is in a watertight compartment. The outlet of the pump is on the side of the unit and the electric motor is mounted on top of the unit.

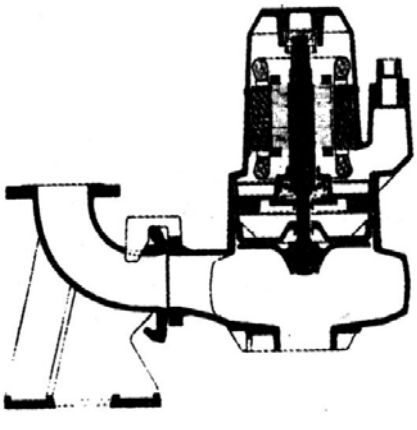

Figure 6.5: Drainage pump

These two characteristics and the fact that it is a single stage pump distinguishes it from the submersible pump, which is commonly known as a submersible pump. (See Section 3.1.5).

It is usually used as a portable unit for smaller pump deliveries and heads and thus doesn't play such an important role in irrigation itself.

Due to their dimensions, neither of these pumps are as a rule suitable for boreholes.

2.1.3 Double-suction single stage pumps

The double-suction single stage pump is basically two general single stage centrifugal pumps mounted back-to-back, each with its own impeller. The two impellers, are, however, driven by the same driver. Strictly speaking, it is therefore two identical pumps coupled in parallel. Just like other pumps coupled in parallel, these types of pumps are meant for larger deliveries.

The two types, namely the vertical and the horizontal split, differ from each other in respect of the manner in which their volute casings open. In the former, the casing divides into two vertical sections and in the latter into two horizontal sections. This casing is also classified as an alternate type of casing, namely a horizontal split casing.

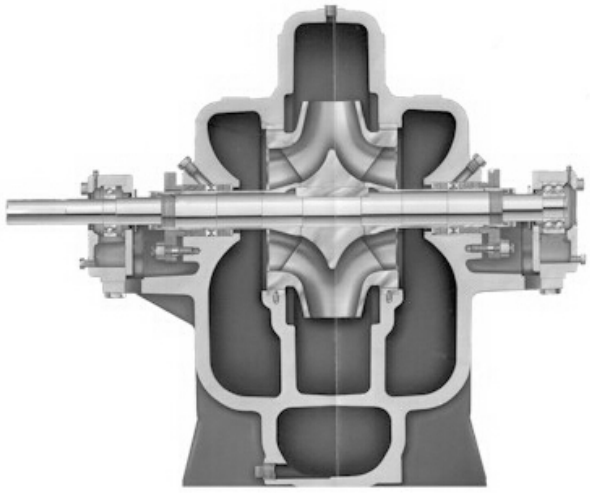

Figure 6.6: Double-suction single centrifugal pump

2.1.4 Multi-stage pumps

A multi-stage pump is a centrifugal pump with a series of impellers arranged in series. The water is thus pumped from one impeller to the next, and just as for pumps coupled in series, it is meant for larger pump heads. The two types, namely the ring profile and the cylinder types, differ from each other in the sense that the former has a series of separate units which can be joined together and the latter is mounted in a cylinder to handle higher pressures within the pump.

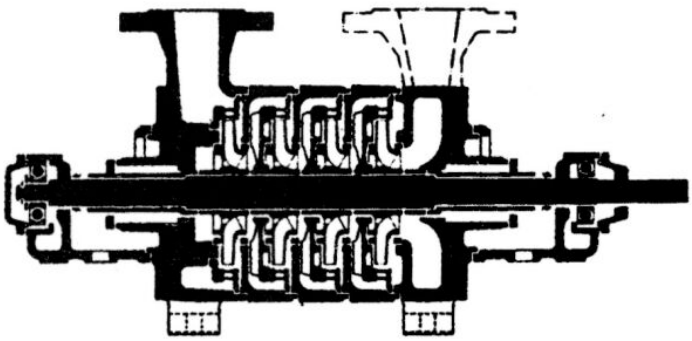

Figure 6.7: Ring type multi-stage centrifugal pump

2.1.5 Submersible multi-stage pumps

Like the submersible single stage pumps, there are also two types of submersible multi-stage pumps, namely the types where the driver is placed above ground and the types where the driver - in the case of an electric motor - is below water level. An example of the former is the vertical turbine that was so popular for boreholes, which in the early days was known as a "bucket pump". The driver is placed above ground and the impellers, which are arranged in series, are driven by a shaft. This type of pump is equipped with axial- or mixed-flow impellers. Impellers or "buckets" can be decreased or increased, as desired. This type of pump is now also provided with a submersible motor that is positioned underneath the pump so that it almost resembles the second type. However, it is still known in the trade as a vertical turbine because the "buckets" can be distinguished from one another.

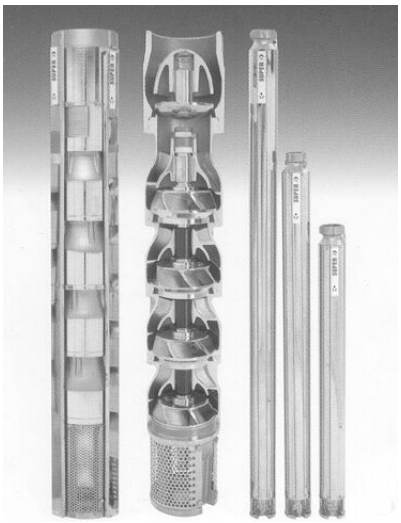

Figure 6.8: Examples of vertical turbines

Pumps that are commonly known as submersible pumps are all classified under the latter group. Unlike the single stage submersible pumps, the electric motors of this group are always mounted underneath the impellers and the water thus flows inside the "pump" until it is let out at the top of the pump. The casing is tubular in shape and axial- or mixed-flow impellers are used. The "buckets" can, however, not be distinguished from one another.

Figure 6.9: Examples of multi-stage submersible pumps

2.2 Positive displacement pumps for irrigation

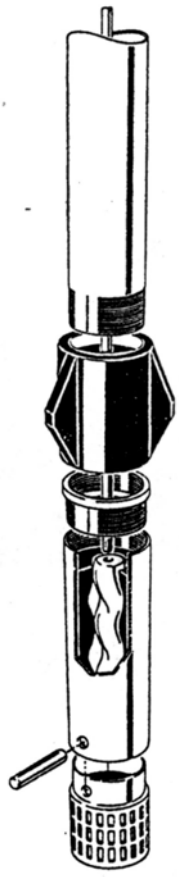

Figure 6.10: Vertical spiral shaped rotary type positive displacement pumps

The spiral shaped rotary type pump is the only positive displacement pump that is currently being used on a significant scale for irrigation. The vertical type that is used in boreholes can especially be considered. The horizontal type can be considered where centrifugal pumps are usually used. The most important characteristic of positive displacement pumps is that they can deliver large pump heads and it is particularly on these grounds that they are worth considering. However, this characteristic is also a disadvantage because if the system delivery should for one reason or another decrease, for e.g. if a stopcock in the system should be closed, the system pressure will increase, which could have serious negative consequences: the pipes may, for e.g. burst, or the pump itself could be damaged. Pressure release valves can, however, rule out this risk.

2.3 Positive displacement pumps for dosing

Piston type reciprocating positive displacement pumps are usually used for dosing chemicals into a system. Here, the characteristic of positive displacement pumps that is normally a disadvantage comes in very handy, because irrespective of the pressure in the system, a constant flow of chemicals is pumped into the system.

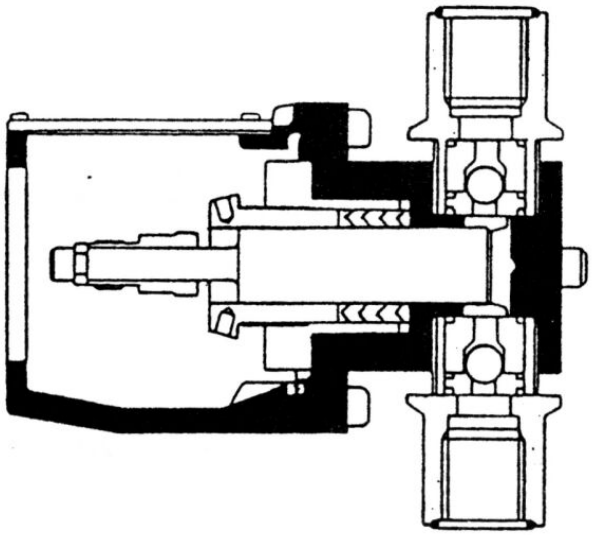

Figure 6.11: Piston type dosing pump

3 Selecting a pump

There is no recipe for the selection of the most suitable pump. Various factors would influence the selection, but in the end, economics has to be the decisive factor and this would include capital, maintenance, replacement and energy costs.

The following general guidelines apply:

- Normal installations: General single stage end-suction centrifugal pumps
- Large suction heads: Submersible pumps
- Large pump deliveries: Double-suction centrifugal pumps, general single stage end-suction centrifugal pumps coupled in parallel
- Large pump heads: Multi-stage centrifugal pumps, general end-suction single-stage pumps coupled in series, positive displacement pumps
- Large pump deliveries and small pump heads: Axial-flow pumps

For each application, there will be a number of suitable types, makes and models, but over the long term, the most economical pump must be chosen. Factors such as after-sales service and personal preferences may also play a part.

An example of a pump curve for a centrifugal pump as published by the pump manufacturer is given in Figure 6.12. It contains the following information:

- Pressure delivery (HQ) curves for the full impeller, as well as a number of selected smaller impeller diameter.
- Pump efficiency [%]
- Nett positive suction height ($NPSH_{required}$) required by the pump [m]
- Drive required for the different impeller diameters [kW]. It can however also be determined by means of the following equations:

$$P = \frac{\rho \, g \, H \, Q}{36\,000 \, \eta} \qquad (6.1)$$

where P = power required [kW]
ρ = density of water [kg/m^3]
g = acceleration of gravity [m/s^2]
H = pump head at duty point [m]
Q = pump delivery at duty point [m^3/h]
η = pump efficiency at duty point [%]

The drive required over an irrigation season can be calculated by multiplying the power required of the pump with the number of hours pumped over the irrigation season.

The published pump curves for pumps are usually the average of a number of pumps tested, i.e. the curve of a specific pump can deviate from that which was published. The pump that was purchased can therefore be tested upon request. There are costs involved and this is only done if the pump delivery and pressure can be measured reasonably accurate.

The point on the pump curve where the system curve crosses the pump curve is called the duty point. The system curve is the curve that indicates the required energy (static height difference + friction loss) vs. the flow in the irrigation system. Although it is seldom necessary to determine a system curve for a choice of pump, it can come in very handy with more intricate pump choices as well as in the evaluation of an existing pump installation. Figure 6.12 shows the pump curve of a typical centrifugal pump.

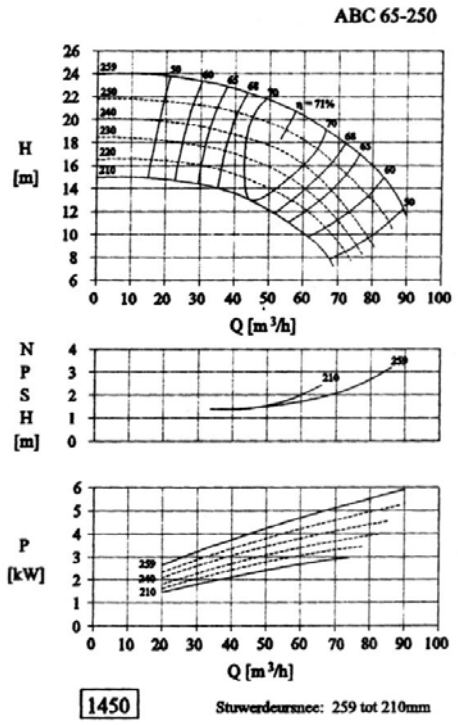

Figure 6.12: Full pump curves of a typical centrifugal pump

Centrifugal pumps are usually identified by what is known as a pump code. This pump code generally assumes the following form:

AAA BBB xxx-yyy

where AAA = make
BBB = pump series
xxx = nominal diameter of outlet in mm or sometimes in cm
yyy = nominal diameter of impeller in mm or sometimes in cm.

There are, however, certain manufacturers who diverge from this form, but it is the exception rather than the rule.

In actual practice, pumps are sometimes identified by means of the inlet and outlet diameters of the pumps if the pump code is not known, but this is not the correct way of doing it. The diameter of the impeller plays a very important part in the performance of centrifugal pumps and the diameter of the full impeller must therefore also be known for correct identification of the pump. The make and series of the pump is just as important for correct identification.

3.1 Series

Pumps can be coupled in series when the required pump head cannot be obtained with only one pump. When two or more pumps are coupled in series, the outlet of the first pump is coupled to the inlet of the second. The same volume of water is thus "pumped" twice. This is exactly what happens with multistage pumps. In a multistage pump, the water is pumped through a series of impellers to deliver a larger pump head.

When pumps are coupled in series, a new pump curve has to be drawn for the combined pumps. This is done by adding up the pump heads of the different pumps for the corresponding pump deliveries, as indicated on the pump curves. Through this, a new pump curve can be drawn for the two (or more) pumps in series.

In Figure 6.13, curves A and B indicate pump curves for two different pumps and the curve marked A + B, the pump curve for the two pumps coupled in series. Points for the pump curves A + B are derived from adding up the corresponding pump heads for a certain pump delivery, i.e. in Figure 6.13, h_3 equals h_1 plus h_2.

Two identical pumps can also be coupled in series in which case the pump heads for two pumps for the corresponding pump delivery will only double.

There are two alternatives for the coupling in series of pumps: The first is to place all the pumps in the same pump-house and the second is to position the pumps at specific places along the length of the same pipe line. In the former alternative, it is necessary to ensure that the pumps, as well as the pipe line, can resist the pressure that will develop. In the second alternative and this is the only motivation for this alternative, pipes of a lower grade can be used because the total pump head is not developed at the water source (first pump station), but along the full length of the pipe line. In such a case, booster pumps are sometimes mentioned. Here, hydraulic gradient must also be carefully considered to comply with the NPSH requirements of all the pumps. A cost estimation will indicate what alternative will give the most economic solution.

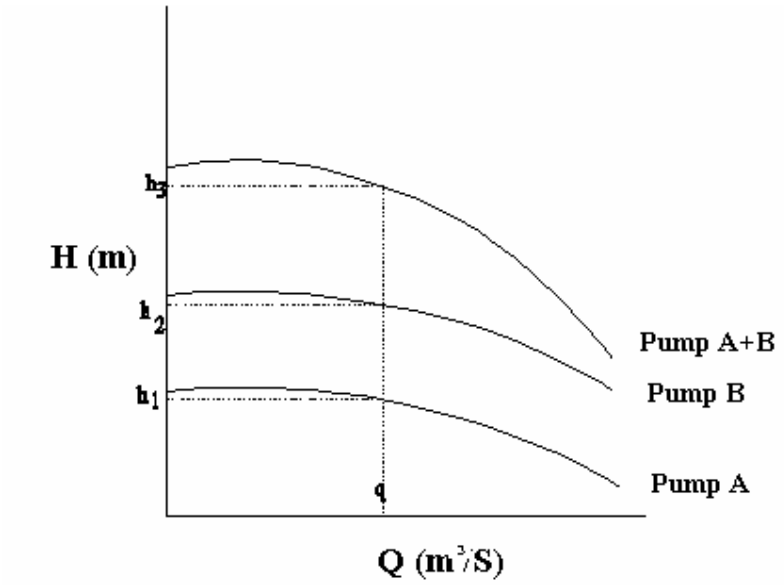

Figure 6.13: Combination of pump curves for pumps coupled in series

With series coupling it must be ensured that one pump does not work without the other. It can be controlled electrically with a no-flow switch between the pumps or with the current measuring of the individual starters. For a diesel unit is more difficult, but if the signal as above is observed, solenoid valves can be used for cutting off the fuel supply to the engines.

3.2 Parallel

Pumps can also be coupled in parallel when the required pump delivery is unobtainable with only one pump, but where the required pump head is attainable. When pumps are coupled in parallel, the outlets of both pumps deliver the water into the same pipe line, unlike pumps that are coupled in series, where the outlet of the one pump is coupled to the inlet of the next pump.

Here the pump deliveries are added up for corresponding pump heads and not for the pump heads for corresponding pump deliveries as, for pumps coupled in series. In Figure 6.14, the curves marked "pump A" indicate the pump curves of a single pump, while the pump curve marked "2 × pump A" indicates the pump curve for two identical pumps coupled in parallel. In this case, Q_2 will be equal to 2 times Q_1.

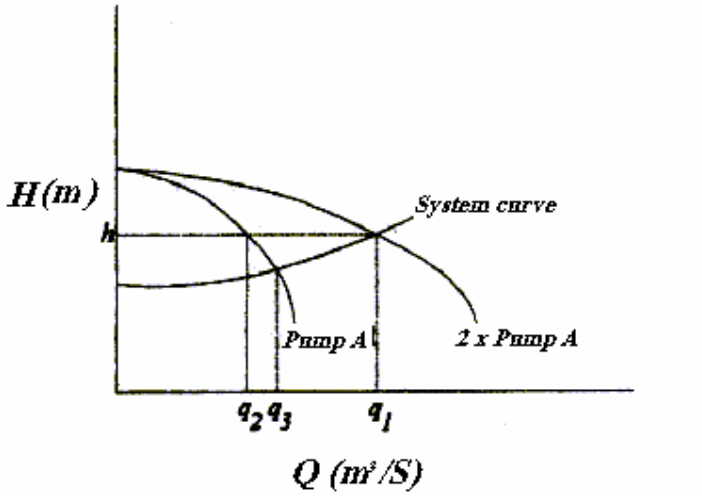

Figure 6.14: System and pump curves for pumps coupled in parallel

Furthermore, it is also not worthwhile coupling two pumps in parallel if their respective pump curves are very flat. Pumps with approximately the same shut-off head are recommended for parallel coupling. If from time to time pumps are used on their own, provision should be made for insulating the non-operative pump to prevent through pumping or back pumping.

The outlet of each pump must be fitted with a control valve and non-return valve. Each pump must also be fitted with an individual vacuum meter and pressure meter. Each motor must also have a voltage meter and especially an ampere meter for easy fault detection. During separate switching on, the one pump may not achieve joint flow. This will usually be the result of the pump not being thoroughly de-aerated or because the nil-flow pressure is lower than the system pressure. The faults can only be detected once these accessories have been fitted.

4 Typical pump positioning for different water sources

The following typical positioning of pumps for different water sources is recommended (Eckard, 1998):

4.1 Rivers

Extraction points for pumps where erosion of riverbanks occur, must be avoided. The extraction point must preferably be at a point where the river flow is straight. The directives for the minimum required water depth and maximum permissible flow speed, as described in Section 6 must be maintained. If the water depth is insufficient, a reservoir must be built next to the riverbank. The pumps must be installed in the reservoir. It is important that the $NPSH_{required}$ by the pump is at all times smaller than the $NPSH_{available}$ on the site. River problems can be solved in one of the following ways:

- Pumps with multi-impellers that turn slowly (1 450 rpm) with good suction ability, can be used. Alternatively, a light pump with good suction ability (that can be moved manually and will not cost too much to replace) can be used down by the river, supplying to the main pump that is situated on top of the dam wall, away from the danger zone.
- Mount the pump on a rail and drag it out of the danger zone when necessary. Quick-coupling delivery pipes, and sometimes a windlass, is necessary here.
- Mount the pump on a frame 4 to 5 times higher than the water level, drive the pump with V-belts with the motor or engine above the floodplain.
- Build a reservoir next to the river bank. Mount pipes in the reservoir. Ensure that the river does not raise the reservoir. Install hoisting scaffoldings to raise or remove the pumps. Use submersible pumps for pumping the water.
- Turbine pumps can be installed at an angle, but they are expensive. Axial flow pumps are ideal for pumping the water, but are also expensive and have head limitations.
- Pumps on floats on the river: A typical float consists of 12 plastic drums of 500 ℓ used for fire fighting. The drums must be filled with polystyrene that will keep them from sinking, even if they are broken. A float with a sharp edge, such as the prow of a boat, will form a vortex under the float. This keeps silt away from the extraction point. A sieve box can be mounted underneath the float, from which the water is extracted. Holes, preferably larger than 10 mm lets the water through. This combination is ideal for good water flow through the box without leaves and branches being sucked in and blocking it. The float must be able to withstand a rise in the river water when the river is in flood. Scaffolding similar to cantilevers can also keep pumps close to the water level and can then be lifted by means of windlasses in case of floods.

When pumping from a river, it is important to remember that fish can react on a horizontal water speed, but they are not sensitive to horizontal water speed. Therefore, to keep them out of the inlet of the suction pipe, the structure around the suction pipe must be built as such that the water flows horizontally at a low speed (0,15 m/s maximum), so that the fish can escape.

4.2 Boreholes

The most popular pumps are the turbine type of pumps used for irrigation and the hydraulic screw for high-pressure conditions and for houses.

4.2.1 Submersible pumps

In order to select the correct size submersible pump, it is essential that the delivery of the borehole should be known. If a too large pump is selected, it can run dry very soon and cause great damage. To prevent this, it is absolutely necessary that the constant maximum delivery of the borehole, in which the pump is to be installed, must be tested for at least the duration of the time that pumping will be done. For a pump in a town the test period is 4 hours, a pump on a

smallholding that is also used for irrigation is 9 hours and for a pump used for major irrigation purposes, the constant maximum flow rate must be determined for 72 hours.

The borehole must preferably be tested during the driest time of the year. A pump, of which the flow rate is not more than 60% of the tested flow rate, is then selected. A further protective measure against "running dry" of the pump – that can be used as alternative or as additional – is a switch that switches off the pump automatically if the water in the borehole sinks lower than a specific point.

In order to obtain a specific required pressure the number of impellers should be increased until the specific point is reached. (The decision on the number of impellers to be used is usually taken by the manufacturer). The increase in pressure is however not entirely directly equal to the number of impellers, mainly because of the greater friction that occurs when more impellers, through which the water must flow, are installed.

The motor is installed beneath the pump, so that it is still under water when the water in the borehole reduces. Submersible pumps can deliver water from 1 to 100 m^3/h. The popular sizes are between 2 and 20 m^3/h. The pump unit, with non-return valve, is connected to a 40 to 50 mm class 10 HDPE pipe. It is let down into the borehole by means of a suitable electrical supply cable, plus earth wire and nylon rope. It is a very simple process and special hoisting equipment is not necessary. The switchgear and capacitors are housed above the ground surface in a box. If larger submersible pumps are installed, a pulley hoisting mechanism might be necessary to move the heavier units in and out of the hole. If the water level in the borehole is mainly above the pump, the water around the motor may heat up and not provide sufficient cooling. The problem can be solved by mounting a pipe casing around the pump and motor, so that the stream of water first flows over the casing around the motor and then to the pump. If the water is very sandy, a fine filter can be installed in the form of a pipe underneath the pump and motor. The filter can be as fine as 500 micron. Always ensure that the pump unit is above the solid sand. It is very important to protect the motor unit against lightning.

One of the causes of surging on the electrical power line is lightning. If lightning strikes a power line, a great amount of electrical energy is fed into the line. This energy addition causes the tension to increase and is known as surging. This surging seeks a path to earth and can therefore damage electrical wiring and equipment where it switches over to the earth and to the earthed frame.

Because the submersible pump with motor, in the nature of its function, is installed in the water below the soil, it is clear that the pump with motor must be thoroughly earthed, which will cause any surging to go through the pump motor. It is therefor extremely important that the pump should be protected against these surges, as well as against the surges caused by induced currents that occur with connection with electrical equipment on the line. In many of the single-phase motors, the surge deflector is built into the frame. Since it is not possible to determine whether the surge deflector is in a good condition to perform its task, it is advisable that an additional surge deflector be installed at a point where its condition can be easily inspected and replaced if necessary.

There are a few directions to be followed in the installation of surge deflectors (Official test results, 1979):

- The switch box with surge deflector must be close to the borehole with pump and motor. Where this is not possible, a distribution box, in which the power supply cable or wires are connected with the pump's cable, must be installed near the borehole. The surge deflector must then be installed in the distribution box.
- Ensure that the switch box or distribution box is thoroughly connected with the pump motor by means of the steel riser pipe and/or a cable. If a polythene riser pipe is used, where no steel cables are present, an earth cable must be provided. This can be either a

steel cable with a diameter surface of at least 20 mm² (5,5 mm thickness) or a uPVC-coated 10 mm² copper cable. The use of copper or aluminium wire for connections is strongly dissuaded, except if it is uPVC-coated over its entire length, because it can lead to corrosion of the pump motor and/or steel pipes.

4.2.2 Hydraulic screw borehole pumps

A hydraulic screw borehole pump consists of three components: The hydraulic screw in the borehole, a special steel pipe in which there are transmition shaft to connect the pump and a power head above the ground. The power supply can then either be an electric motor or an internal combustion engine. The pump functions positively, therefore ensure that a valve is never installed for switching off the water, because the connection rod can break. The pumps can accomplish very high pressures, up to 500 m and are effective from low to high flow. The flow limits are very similar to the submersible pumps, i.e. from 1 to 100 m³/h. When a driving source is a single- phase motor, switch-on problems will be experienced if the motor is not at least 50% more than the required power source size. The reason is that the pump requires a high starting torsional moment. As soon as it in operation, the drive is less.

The installation of pumps is a specialised task and must be erected correctly by an experienced person. Firstly, a hoisting mechanism that must sometimes be able to pick up 1 ton is necessary, depending on the size and length of steel pipe at the bottom of the borehole. The special 3 m lengths of pipe with parallel thread must be thoroughly secured, or the pump will fall into the hole. The rods in the pipe work with counter clockwise thread. After the pump with pipes and rods is let down into the hole, the head must be connected with a portion of pipe, because the last rod used, is not a full length. The rods must then be raised by about 25 mm to facilitate pre-stressing. It is necessary to balance the stretch that the rods will undergo with full load.

4.2.3 Turbine pumps

Turbine pumps are available in sizes of 100 mm to 200 mm and even larger. They consist of multiphase impellers in the bottom of the borehole such as those in a submersible pump, as well as steel connection pipes and rods to the head on the surface such as those of the hydraulic screw. The flow rates can be much greater than the two types of pumps discussed above. The power source can be the same as that of the hydraulic screw or a motor or internal combustion engine. Installation requires expertise and heavy equipment is necessary.

4.2 Sand points

Centrifugal pumps cannot suck in air, therefor ensure that the suction pipeline that extracts water from the sand, is filled with water.

Two solutions are recommended to prevent the problem (Eckard, 1998).

- Drill a 600 mm borehole along the dam wall where the pump is to be installed. Place a 600 mm diameter steel pipe in the hole like a borehole lining. The depth must be such that the total volume in the borehole lining pipe is twice the volume in the sandpit pipe and the sand points. The end of the pipe must be sealed. Place a borehole pump in the lining pipe and seal the connection airtight. Connect the sand point supply pipe to the lining pipe. Fill the lining pipe with water. The water level in the lining pipe will subside. Because everything is sealed airtight, a vacuum will be created. The vacuum will be displaced to the sand points that will suck up the water to the borehole lining-pipe. The sand points will then supplement the displaced water in the lining pipe. The secret is to make all the connections airtight.

- The other system is to connect a centrifugal pump at the bottom end of an air vessle. Of the same volume as the borehole lining mentioned above. The sand pit suction pipe is connected

to the top of the air vessle The air jug is filled with water again. The pump is switched on, the water level in the air vessle drops and a vacuum that sucks water into the sand pit is created. Everything must be airtight, the quality of material will determine the life span of the system and the vessle or lining must naturally be strong enough to resist the vacuum.

4.4 Earth dams

If the dam wall is not too high (5 m water) a siphon with a vacuum tank can be considered. The purpose of the tank is to keep the suction pipe de-aerated at all times. Water must preferably be extracted from the upper layer of a dam. A sieve on the suction pipe of a pump is recommended when water is pumped directly from a river. Sticks and leaves can be kept out of the filter this way from the very start. A suction pipe that rises 3 m can be as long as 50 m and will function without problems as long as there is a gradual rise. A pump unit on floats can sometimes be considered. Such floats should be anchored thoroughly, because the wind can cause damage.

5 Protection of pumps against waterhammer

Water hammer is the increase in pressure in a pipeline resulting from a sudden variation of the water velocity, because e.g. the flow is suddenly started or ceased. If water that flows in the pipeline is suddenly brought to a standstill, by the sudden closing of a valve, an increase in pressure is created resulting from the change in momentum of the water. If water hammer is not controlled, it may cause great damage to the system. It may be necessary to take precautions to lower pressures. Some of these precautions, which can be used under different circumstances, are:

- Surge tanks
- Air chambers or collectors
- Pressure relief valves
- One-way valves (supplementary)
- Pump flywheels

6 Installation of pumps

When receiving the pump, ensure that it is not damaged and that all the parts are present.

6.1 General

- Select the pump site as such that it can be reached easily for regular inspection and maintenance.
- Foundations must be sturdy to reduce vibrations and strong enough to prevent distortion. Where the drive is an electric motor, the foundation must be at least 1,5 times the combined mass of the pump and the motor and for diesel engines at least three times the mass. Also ensure that the foundation surface is large enough so that the permissible pressure is not exceeded.
- Centrifugal pumps should be installed as close as possible to the water source, so that the suction pipe length and static suction head is limited to a minimum. Always ensure that the NPSH requirements of the pump are adhered to.

6.2 Suction side

Most pump problems are the result of poor suction side design and installation. The suction side design and installation must be such that turbulence in the pipe is prevented and the imbibing and collection of air at higher places in the suction pipe must be prevented. The following points are important:

- Suction pipes must be as short as possible.
- The flow velocity in suction pipes must be $\leq$ 1,5 m/s. The greater the flow velocity, the greater the chance that turbulence in the pipe can occur and can result in the pipe being fed unevenly. The friction losses are also higher. The chance of vortex forming in the pump hole is also higher and can cause air to be sucked in. The suction pipe must be at least one diameter size larger than the pump inlet.
- Where a 90° bend is used, the radius must be at least (2D + 100 mm), where D is the suction pipe diameter. Where bends are made from welded pieces, a 90° bend must consist of at least 5 segments. Welded seams must be smooth.

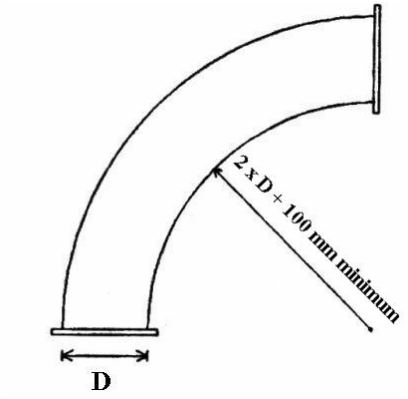

Figure 6.15: Bends

- The length of eccentric reducers must be at least $5(D_2-D_1)$, where D_2 is the greater and D_1 the smaller suction pipe diameter (See Figure 6.16).

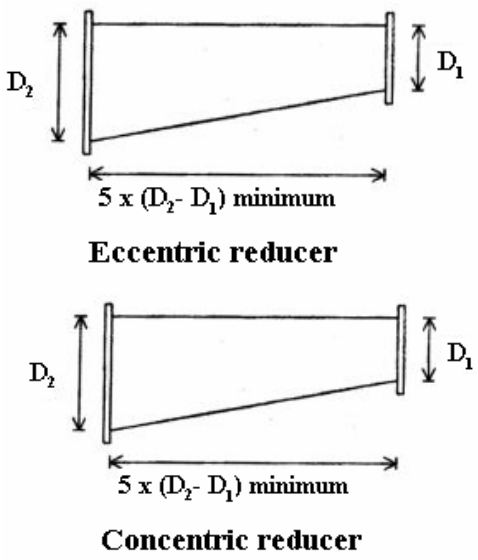

Figure 6.16: Reducers

- If pumping is from a T-piece from the main pipe, there must be a straight section of at least 2D between the T-piece and the reducer. If possible, it is better to use a Y-connection with the main pipe.

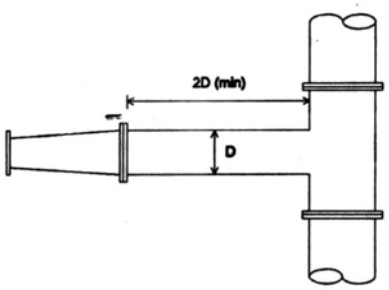

Figure 6.17: T-pieces

- The suction pipe must be airtight and without high points where air can collect. The suction pipe must be laid with a gradual upward slope to the pump. If the pump has a positive suction head, the suction pipe must be installed with a gradual downward slope to the pump to prevent the forming of air bubbles. Therefor, use eccentric reducers at pump inlet with the straight side on top. Where valves are used in a suction pipe, the handle of the valve must lie horizontally to prevent air-filled pockets in the valve. In Figure 6.18A indicates the correct method and B the incorrect method, because air can collect at B in the suction pipe and form a bottleneck in the suction pipe.

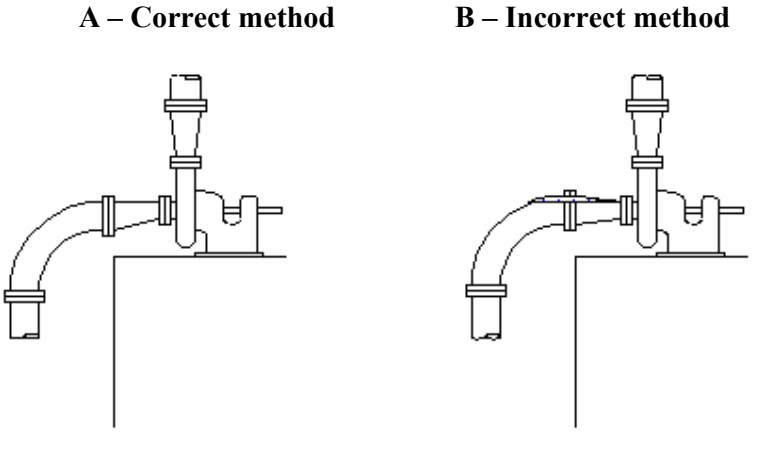

Figure 6.18: Eccentric and concentric reducers

- The suction pipe must be deep enough beneath the water level to prevent a vortex being formed and air sucked in. Directives are given in Table 6.1, for the minimum water depth

above the suction pipe inlet, according to the inlet flow velocity of the water in the suction pipe.

Table 6.1: Minimum water depth above suction pipe inlet

Inlet flow speed (m/s)	Minimum water depth (m)
1,0	0,3
2,0	1,1
3,0	2,0

- It is also important that the distances as shown in Figure 6.19 are maintained in the pump hole.

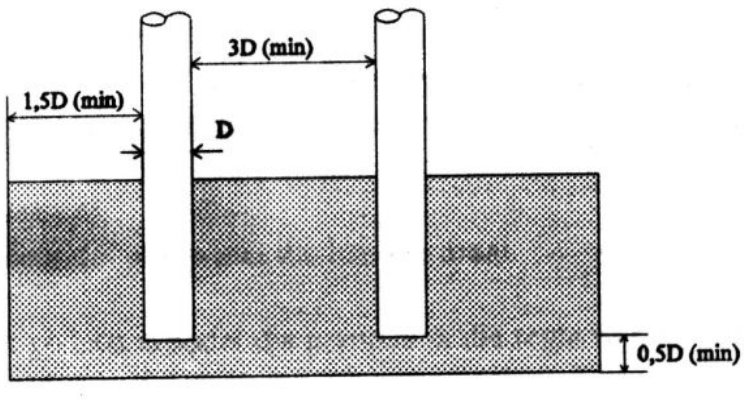

Figure 6.19: Distances between suction pipes and sides and bottom of pump hole

- Bell-shaped inlets are recommended, because they have the benefit that the flow speed at the inlet is low and that sand and stones cannot be sucked in as easily.
- Free-area of foot valves must be at least one-and-a-half times the suction pipe diameter. Where suction head is a limiting factor, foot valves, that usually result in a high friction loss, must be avoided.
- The free area of the sieve before the suction pipe must be at least four times that of the suction pipe to prevent alien materials from blocking the foot valve. Guide sieves must be mounted at least eight times the suction pipe diameter before the suction eye of the pump to prevent that turbulence causes cavitation. If it is necessary to mount the sieve closer to the pump, a stroombelyner current alligner must be mounted.
- Sieves must have holes with a diameter of 6 to 12 mm and the total area of the holes must be six times the suction pipe area.
- Water supply to the pump hole must also be such that it does not cause the suction pipe to suck in air. It is especially a problem where the pump hole is fed by another pipeline. In that case the supply pipeline must be placed away from the suction pipe so that the suction pipe does not suck in air bubbles that form when the water enters the pump hole.
- Suction pipes or drainage pipes must fit naturally and not be forced in by means of flange bolts. It must also be supported independently near the pump so as not to place stress on the pump casing.

6.3 Delivery side

- Delivery pipes must never be smaller than the pump outlet. The velocity in the deliver pipe must be $\leq$ 3 m/s (KSB). It is recommended that a concentric reducer be connected directly after the pump outlet, so that the pipe diameter enlarges to twice the nominal diameters of the pump outlet. After this, an bend can follow and if necessary, a non-return valve, followed by the sluice valve and if necessary, a second concentric bend that enlarges the pipe diameter to the same size as the delivery pipe. If the pump head is >15m, or the delivery pipe is very long, a non-return valve must be installed (KSB). The non-return valve protects the pump and foot valve against water hammer when the pump is switched off. Avoid sharp bends that cause unnecessary friction losses. Some pumps are manufactured in such a way that the pump casing can rotate so the pump outlet can be swung to the required direction or as close as possible to it. Give preference to these pumps, if they can be of assistance.
- Pressure meters can also be provided at a pump. A pressure meter just upstream of the sluice valve will show the pressure of the pump head minus the static head and friction upstream thereof and is handy when the pump is evaluated. A pressure meter just downstream of the sluice valve will come in handy if the system pressure is to be set by means of the sluice valve to prevent overloading of the motor.

6.4 Final finishing of installation

- Flush the entire system to get rid of alien materials such as welding beads, dirt, etc., before the pump is finally mounted. These materials can be sucked into the pump and cause damage.
- Test the alignment before the pump is put into operation. This can be done by placing a straight edge over the connection flanges at four points, 90° apart. This straight edge must rest proportionally on all the points on the flanges to ensure parallel alignment. Also measure the distance between the interfaces with 90° intervals, by using an inside calliper or a taper guage. When measurements are the same at all points, the unit is lined up. When necessary, the lining can be adjusted by means of shims between the base of the pump or the drive bases. A pliable connection will not compensate for disproportionate alignment. Inaccurate alignment causes vibrations and excessive wear.
- Oil is usually drained from the pump before dispatch. Ensure that the oil levels are correct before the pump is put into operation. Also ensure that greased pumps do not have too much grease.
- Ensure that all the rotating parts are free by turning the pump by hand.
- Ensure that the electrical wiring has been done correctly so that the pump axle turns in the right direction.

It is definitely worth giving careful attention to the installation to ensure that it is done correctly to eliminate any later problems.

6.5 Pump casing

It is evident that motors and engines should be protected against dust and rain. With the erection of the pump house, it must be kept in mind that the pump will at some time or other need attention and provision must be made for easy removal of the pump.

The room, in which the pump is installed, must have cross ventilation. There must also be enough space around the pumps for free movement – one meter is sufficient. Hoisting mechanisms for heavy pumps will sometimes be essential. The electric cables of the switchgear must lie in a cement trench and must not be buried. The non-return valves must preferably be anchored on the same foundation as the pumps. Suction pipes must be securely supported to eliminate differential sagging between full-water and empty-pipe conditions. Electrical pump unit concrete foundations must be 1,5 times heavier than the pump unit and a diesel unit's foundation must be 3 times heavier. Concrete foundation must be completely dry before the pump is placed on them. Fittings

must effectuate smooth flow as per directions already discussed. Drainage trenches in the pump house are very important to ensure dry conditions inside the pump house.

Figure 6.20: Ventilation of a pump house.

7 Evaluation of pumps

The evaluation of a pump can only be done if the pressure at the pump, as well as the pump delivery can be measured correctly. If the drive is an electric motor and an ampere meter is provided, the current can also serve as an indication whether the pump is still functioning as initially designed. If the motor draws a stronger current, it indicates that the pump delivery has increased, possibly as a result of sprinkler nozzles that become worn, leaks in pipes, etc. If it drops, it may be as a result of the impeller that is worn and no longer satisfies the initial service point.

A hydraulic test on the pump can be done as follows (Mulder, 1996):

NB: To do this test, there must be a sluice valve on the delivery side of the pump, a pressure gauge between the pump outlet and the sluice valve, as well as a water measuring apparatus somewhere in the system, that can register the full pump flow rate. The water measuring apparatus does not necessarily have to be in the system or be permanently installed. A measuring notch or flume, which is correctly installed, can be sufficient in some cases. If a flow meter has been installed or connected, the flow is measured by taking the volumetric reading on the meter at the beginning and at the end of a certain peak period

- Switch on the pump (centrifugal pump only), with a closed sluice valve and measure the pressure as soon as the pump reached its maximum pump head. Determine the height difference between the measuring point (position of pressure gauge) and the water level in the source (H_s) and add this to the pressure gauge reading to obtain a value for the starting pressure (H_0). Therefore, $H_0 = H_s$ + pressure gauge reading. The pressure gauge reading must also be converted to metre:

10 kPa= 1 m, and 10 m = 1 bar

Because there is no flow, the suction side losses will be nil.

When a vacuum meter is used upstream of the pump, it can be added to the pressure gauge reading together with height difference between the vacuum meter, to obtain a value for H_0. If the vacuum meter registers a reading of nil with a positive suction height, for example, then the pump is lower than the water level of the water source, this pressure can also be determined by means of a pressure gauge.

- Open the sluice valve slightly to approximately half of the pumps normal delivery and measure the pump delivery (Q_1), as well as the pressure gauge reading, plus the height difference (H_s), plus the friction losses and secondary losses upstream of the measuring point for Q_1 (Hf_1), and add this together to obtain the value of the total pressure (H_1). Therefore, $H_1 = H_s$ + pressure gauge reading + Hf_1. A vacuum meter can also be used here as described in the previous step.

  If the friction and secondary losses on the suction side cannot be determined, ignore it. It does have an influence and if possible, must be determined, but it will not make the test meaningless if it is not determined. The values for H_1 and H_2 will be marginally less than the actual values thereof.

- Now open the sluice valve completely, measure the pump delivery (Q_2) and determine a value for H_2, as in the step above. Therefore, $H_2 = H_s$ + pressure gauge reading + Hf_2. A vacuum meter can also be used here as described in the previous step. Note that the friction and secondary losses will now be greater as a result of a greater pump delivery. This point should be the point where the system curve and pump curve cut each other under normal circumstances and is actually the service point of the pump.

- Now plot the values for $[H_0; Q=0\}$, $[H_1; Q_1\}$ and $[H_2; Q_2]$ on the original pump curve on which the system curve is indicated and compare it with the following examples to obtain an indication of the problem, if any. The system curve is obtained by plotting the system pressure (H in m) against the system capacity (Q in m^3/h) on the pump curve graph.

These three points determined on-site, are the minimum number of points required. It can however be too few to find the problem and then alternative pump delivery points must also be determined. The more points, the better. That is to say, the two points, namely valve completely closed and valve completely open is compulsory, and then at least one in between.

The speed, at which the pump is driven, must also be measured, especially if the motor is not an electric motor running at a standard speed. Four representative cases of what can be found with the tests in practice are now discussed.

Case 1: All three the points determined by the tests, fall on the pump curve, but none on the system curve. The system curve is therefore incorrect and indicates that the design was done incorrectly or the pump is utilised differently from the purpose for which it was initially intended.

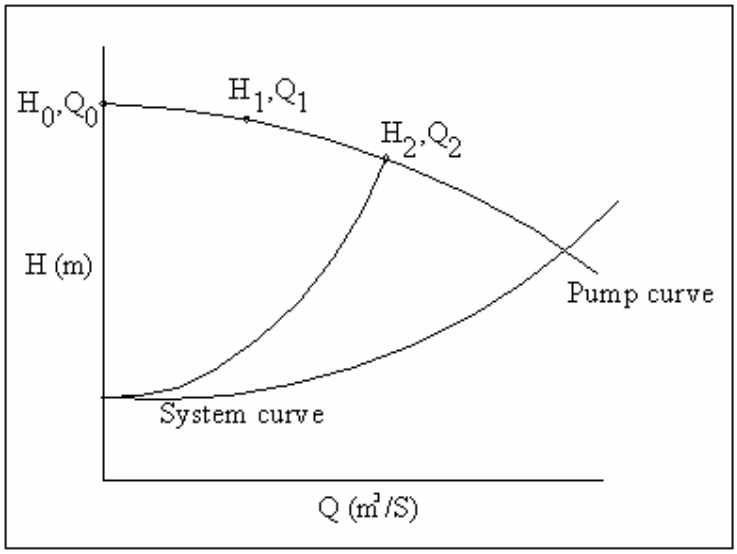

Figure 6.21: Values on curves for pump head and flow rate - Case 1

Case 2: The point H_0; Q = O agrees with the pump curve, but not the other two and point $H_2;Q_2$ falls on the system curve. This indicates that there is a problem with the pump, such as a blockage in the impeller, casing or even in the suction pipe.

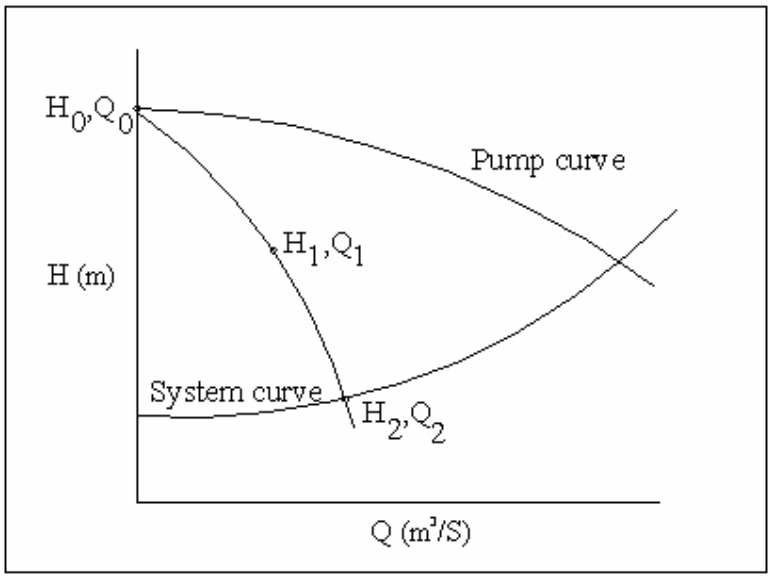

Figure 6.22: Values on curves for pump head and flow rate - Case 2

Case 3: The points for $H_0;Q=0$ and $H_1;Q_1$ falls on the pump curve, but not $H_2;Q_2$. This indicates that the pump functions correctly up to a certain point and is then not able to provide the normal pump head and pump delivery. This can possibly indicate that the pump begins to cavitate at a certain point as a result of a too high suction head.

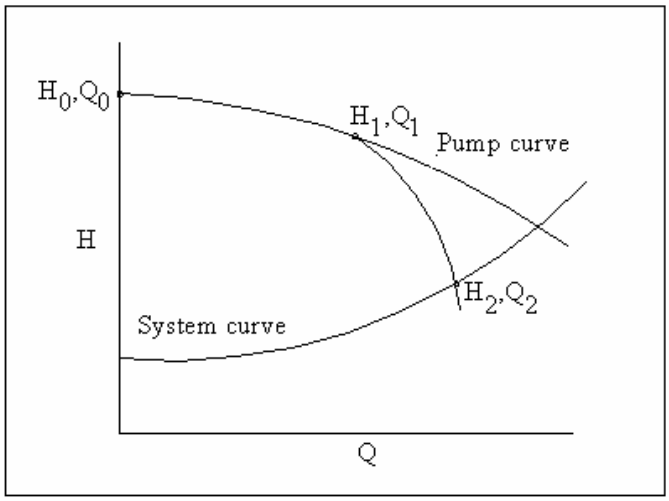

Figure 6.23: Values on curves for pump head and flow rate - Case 3

Case 4: None of the points fall on the pump curve, but $H_2;Q_2$ falls on the system curve. The pump therefore does not function as on the pump curve and this indicates that the wrong pump was installed, that the pump runs at the wrong speed, that the impeller is cut or that the pump is driven in the wrong direction. A pump that turns in the wrong direction, usually delivers a pump head of approximately two thirds of those on the pump curve.

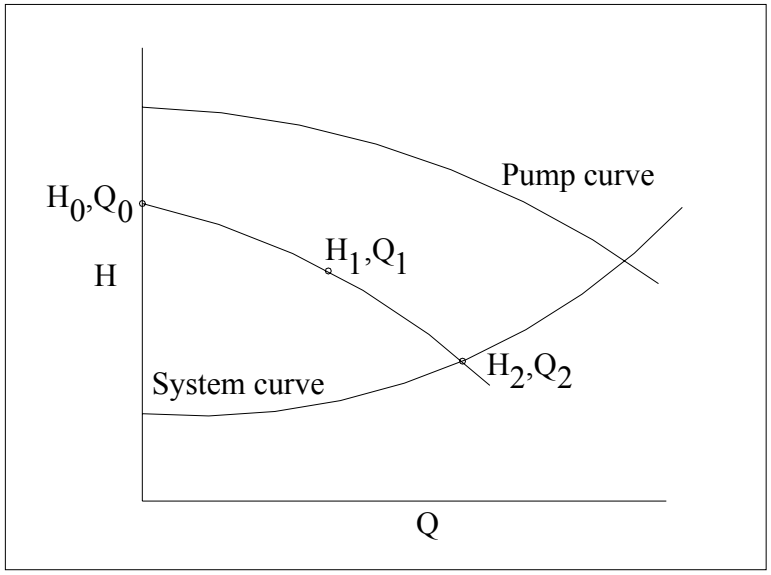

Figure 6.24: Values on curves for pump head and flow rate - Case 4

A hydraulic test on the site is very handy and if possible, it should be done regularly. The provision of an ampere meter is however a much simpler method of observing changes in functioning over the life span of a pump.

8 Operation of pumps

Centrifugal pumps use the atmospheric pressure to push the liquid up into the suction pipe to a partial vacuum that occurs at the eye of the impeller as a result of the displacement of liquid. If the pressure at

the eye of the impeller should drop lower than the vapour pressure of the liquid at that temperature at any stage, evaporation will occur within the liquid. As the vapour bubbles move through the high-pressure area with the liquid to the impeller, the bubbles will collapse. The forming and collapsing of gas-filled hollows in the liquid that is being pumped, is known as cavitation. The liquid now strikes the impeller surface with a tremendous speed and the high momentous pressure at these points can consequently erode the metal of the impellers.

The detrimental consequences of cavitation are:

- Erosion on the surface where cavitation takes place.
- A noticeable reduction of utilisation degree as a result of the forming of vapour that reduces the volume of the liquid.
- Pump noise increases as a result of vibration and pulsing.

It is clear that, to prevent cavitation of a pump and to ensure that a pump is functioning effectively, there must be a certain minimum pressure at the eye of the impeller. The pressure at the suction side of the pump becomes the net positive suction head ($NSPH_{required}$) required from a pump mentioned. It varies from pump to pump and is usually provided by the pump manufacturer (Section 3). The net positive suction head available on the site ($NSPH_{available}$) must be greater than the $NSPH_{required}$ of the pump.

8.1 De-aeration

Fill the pump casing and suction pipe with water before the pump is switched on. De-aeration can be done in four different ways:

- **Vacuum pump**

A manual pump is installed on the pump casing, which pumps out all the air each time the pump is to be used.

- **Foot valves**

It is a one-way valve installed on the inlet of the suction pipe which prevents the water from the pump from draining out of the suction pipe as soon as the pump is switched off. However, foot valves clog easily, with consequent high friction losses, and they are seldom totally dependable.

- **Priming from supply pipe**

A pipe is installed in the supply pipe on the downstream side of the valve and it is attached to the pump casing. The pipe line is also provided with a valve and the pump is then primed by opening this valve to displace the air in the pump casing and suction pipe with the water in the supply pipe.

- **Positive suction head**

The pump is installed in the pump sump at a lower level than the water level, which ensures that there will always be water in the pump casing and suction pipe. This is the ideal, but not always possible. Problems with NPSH are also ruled out in this way.

8.2 Putting pumps into operation

First check the alignment. Ensure that all the rotating parts are free by turning them manually. During commencement of operation, note the quantity of water leaking at the pump gland. If excessive leaking occurs, the gland nuts must be tightened slowly and evenly on both sides until the water just drips slowly. Ensure however that the pump gland is not tightened too much, because it can lead to heat build-up that can damage the pump shaft. Ensure that the pump runs in the right direction during use, by switching it on at closed valve for a while. Look at the rotation direction of the pump shaft and compare it with the direction of the arrow as indicated on the pump. Check the oil levels in oil-filled pumps. Greased pumps must be checked for excessive grease. Fill the pump casing and suction pipe with water before switching on the pump. The reason

therefor is that when the pump is not switched on at closed valve, it then pumps at a low pump head, causing a high pump-delivery that can lead to overloading and even damage to the motor. If Escom power is used, it will also keep the kVA demand low. Open the cooling water on the mechanical seals and bearings if they are part of the unit. Switch on the pump. As soon as the pump runs on full speed and the required pump head is reached, the sluice valve can be opened slowly. Check the reading on the ampere meter to ensure that the permissible value is not exceeded.

The pump must not be allowed to operate at closed valve for too long, since overheating can occur. If the pump has been provided with an axial flow impeller, the drive requirement and downstream pressure will drop if the delivery increases. A stop valve is therefor not necessary. Where a number of pumps are served from one transformer, it is also important to switch on the pumps in order of large to small. It also keeps the kPa demand peak low.

8.3 Switching off the pumps

It is advisable to close the sluice valve just before switching off the pump, because it combats water hammer and will also keep water in the pipes that can possibly be used for the next de-aeration of the pump. Also close the small valve that closes off the vacuum meter on the suction side before the pump is switched off.

9 Maintenance of pumps

The pump manufacturer usually provides a maintenance schedule that indicates the maintenance to be done. As with any type of equipment, it is very important that the necessary maintenance is done regularly to ensure that the installation can function efficiently and that the life span of the installation is prolonged. The pump must always run smoothly without any vibrations. The water depth on the suction side as well as the power consumption must also be regularly monitored.

Over and above the manufacturer's schedule, the following can serve as directives for the maintenance of the centrifugal pumps:

- Check the alignment every six months
- Replace the oil every six months if applicable. If the oil level drops, new oil must be added
- Check and clean the bearings every 1 000 operating hours
- Inspect all wearing parts regularly and do a hydraulic test. A simpler test can also be done by just closing the sluice valve and taking a reading on the pressure meter that is installed upstream of the sluice valve. If the pressure drops in relation to when the pump was initially installed, it indicates excessive wear. This test should be sufficient for maintenance purposes. If there is a suspicion that the installation does not function correctly, the complete test can be done, as described in Section 6. By monitoring the ampere reading, it can be determined whether the pump's service point changes with time.
- Inspect the gland leakage regularly. It must leak slightly, because it is lubricated by water. Also feel the pump for excessive vibrations.

It is also worthwhile to dismantle the pump sometimes and to concentrate on the following:

- Impeller clearance at collar – skim the impeller neck to give clearance and mount the correct wear rings.
- Inspect the pump shaft for damage
- Replace casings f necessary
- Clean surfaces of impellers, pump casing, etc., paint if necessary
- Replace gaskets and O-rings and bearings
- Check all adapter parts.

The following table can be used as directives for maintenance of centrifugal pumps:

Table 6.2: Typical maintenance schedule for pumps

Monitor	Monthly	1 000 Operating hours	Bi-annually	Annually
Check alignment / settings			X	
Replace oil			X	
Inspect bearings and clean		X		
Inspect all parts for wear and do hydraulic test*	X			
Inspect the gland packing leakage (it must leak slightly, because it is lubricated by water)	X			
Replace the gland packing				X
Inspect cables and electric equipment			X	

*This test can be done by closing the stop valve and taking a pressure reading on the manometer mounted on the outlet of the pump. If the pressure drops, compared to the reading taken when the pump was new, it indicates wear (Section 6). As mentioned previously, the pump gland packing must leak slowly when pumping is done. If the gasket can be compressed with the width of the gasket ring or more (as a result of the tighten up process), the gland packing must be replaced.

The correct method to repack the pump pressure gasket, is as follows (Mulder, 2002):

- Loosen the gland packing nuts slightly, drain the liquid where applicable, remove the gland packing nuts and pull out the gland packing guide.
- Remove the gland packing carefully and clean the gland area. If the gland packing is not reusable, keep it for later inspection so that the problem can be identified.
- Test the shaft for concentricity and whether it is straight. The maximum run-out may not be more than 0,025 micron. The surface of the shaft must also be free of scratches, grooves or any other irregularities.
- Inspect the gland packing guide for correct fitment and general condition. The inner radial clearance may not be more than 0,4 mm. The outer radial clearance may not be more than half of the inner radial clearance.
- Test the clearance between the bush at the neck of the gland packing clearance and the shaft. If it is more than 0,25 mm, it is possible that the gasket can be pulled through. Precautions must be taken to prevent this.
- Measure the depth of the gland packing clearance to determine how many gasket rings are required.
- Gland packing are usually supplied in spiral form, long pieces or shaped rings. When it is supplied in the shape of continuous lengths, it must first be cut into rings. Roll the gasket around the shaft or other round object of the same diameter. In order to cut the rings correctly, two parallel lines are drawn on the gasket with the distance between the lines equal to the breadth of the gasket.
- Then cut the rings at an angle of 45° with the aid of two parallel lines.
- The points of metal and pressed rings can be pulled apart axially to make them fit. If the rings cannot be pulled open without the possibility of damage, it can be cut with a hinge-cut, by cutting two-thirds through the gasket.
- First test the first ring by packing it around the shaft before any more rings are cut out. If it is compatible with the type of gasket, an anti-seize agent can be applied to the inside and outside of the rings.
- Test if the shaft can turn freely.
- Fit each ring separately. A split casing can be used with the gland packing guide to push each ring into position. By measuring the depth to the ring, a test can be done to determine whether each ring is in position. When the graphite of PTFE gaskets is used, the rings must be shifted into position and not be pushed hard or knocked in.
- Ring joints must be spaced at 120°.

- Test whether the shaft can be turned after each individual ring is fitted.
- Place the pressure gauge perpendicular against the last gasket ring and tighten the nuts with the fingers.
- Turn the shaft to ensure that it does not touch the gland packing guide.
- Place pressure on the gland packing by switching on the pump and ensure that there is no air trapped in the gland packing. A gland packing must leak and leakage must begin soon after the pump is switched on. The pump may overheat before leakage begins, but in that case the pump must be switched off and given time to cool down. When it is switched on again, leakage must occur. If not, the packing must be done from scratch. Gland packing nuts may not be loosened to slacken the gland packing.
- After the pump has run for 10 minutes, the gland packing nut must be tightened with a sixth turn. This process can be repeated, also at 10 minute intervals with a sixth turn until the leakage has reached an acceptable level.
- When this adjustment is completed, there must be a drip leakage, so that overheating does not occur. If the gland packing is carefully and thoroughly run in, the leakage may be eliminated, especially under light working conditions.
- Successive adjustments can be done the same way when the pump is running under normal conditions.

10 Fault detection

Problems with pumps can be classified as a mechanical or a functional problem. Both can be as a result of a hydraulic problem.

- **Mechanical breakdown**

Mechanical breakdown is best detected by means of a physical examination. The pump must be dismantled carefully and all the damage and the location thereof examined. To determine the causes of mechanical breakdown, the following can be checked:

- Breaks: By inspecting the broken parts, it can be determined whether the break was as a result of poor materials, weak spots in material or fatigue. In the case of the first two reasons, the part can be replaced without reason for concern. In the third case however, the hydraulic conditions must be checked to determine the specific cause of the breakage.
- Scratches: The location of the scratches can indicate if the pump was manufactured and mounted correctly and the behaviour of the pump shaft. Axial and radial powers on the pump shaft are also influenced by the undesirable and unplanned application of the pump.
- Wear: Distinguish between wear, cavitation and recirculation. Wear occurs as a result of solids particles in the water, cavitation resulting from collapse of air pockets. Bubbles and recirculation resulting from eddying of water in the impeller. The location of the wear will indicate whether it occurred as a result of cavitation or recirculation.
- Corrosion: Distinguish between wear and corrosion by inspecting the surface condition of the metal. Wear will make the surface smooth and corrosion will make it coarse and all the surfaces inside the pump will be affected.

The following photographs show the influence of different factors on pumps impellers (Barnard, 2002):

Figure 6.25: Impeller condition as a result of excessive application of chlorine with the pump

Figure 6.26: Impeller condition of a pump that had to function against a closed valve for a long period. The casing burst open.

Figure 6.27: Impeller condition as a result of air leakage on the suction side of the pump (Cavitation at the eye of the impeller)

Figure 6.28: Impeller condition as a result of a key landing up in the suction side of the impeller (The same condition as when the pump has run dry for a while)

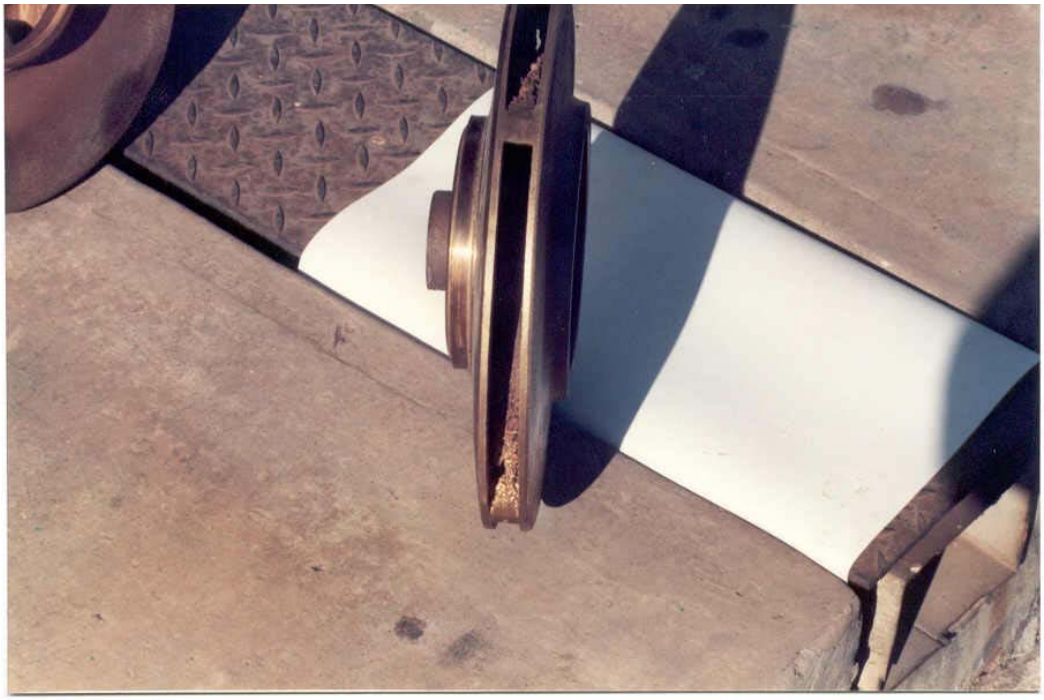

Figure 6.29: Impeller condition as a result of a suction pipe that is too small. The eccentric adapter on the inlet side of the pump is too short. Inside of fins is damaged as a result of cavitation. Ball bearings on suction side of pump became noisy.

Figure 6.30: Impeller condition as a result of a suction pipe that is too small. Bearings have not failed yet.

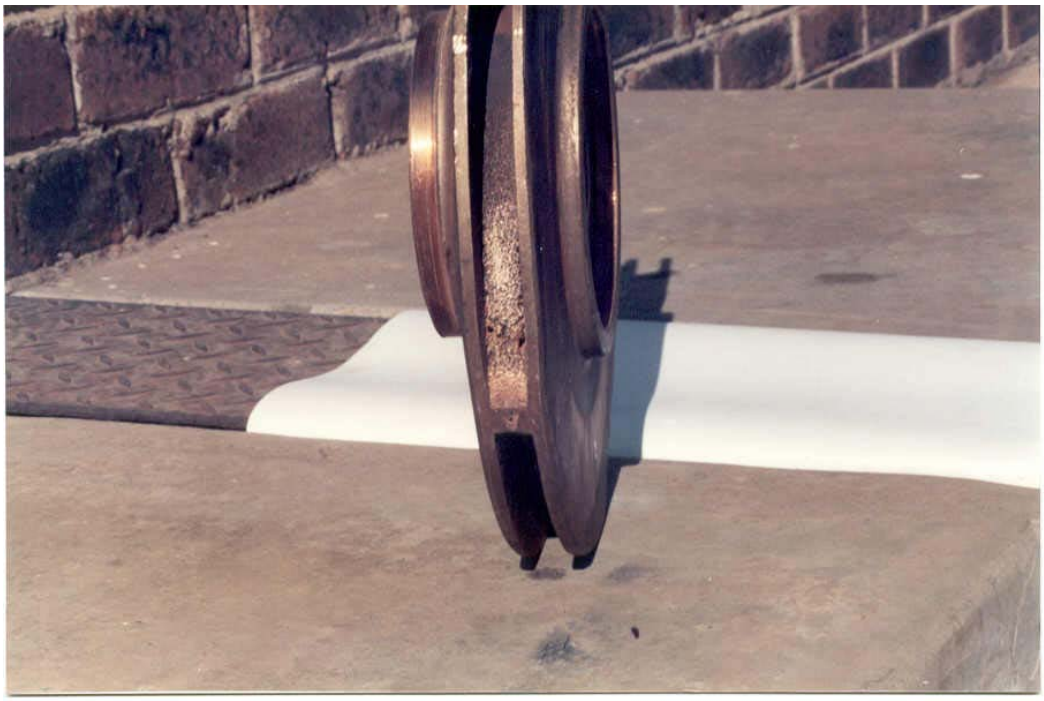

Figure 6.31: Impeller condition as a result of dirty suction sieve or frog catcher. Cavitation causes heat build-up

Figure 6.32: Impeller condition as a result of water-hammer on casing. The base plate was not bolted tight. The pressure control valve closed when power was switched off. Pump casing cracked in the centre) and pieces of fins were wrenched out

- **Hydraulic problems**

If a pump does not function as required, the hydraulic test as discussed in Section 6 can be done. Table 6.3 indicates the more common problems experienced with centrifugal pumps, as well as the possible causes and solutions.

Table 6.3: Trouble shooting table for pumps (Mulder, 2001)

Problem	Possible causes	Solution
Pump does not deliver	Pump is not sufficiently de-aerated, air is trapped in suction pipe	Switch off pump and de-aerate thoroughly
	Air leaks into suction line or stuffing box	Repair leaks or re-pack stuffing box
	Suction pipe inlet not deep enough under water	Ensure that there is sufficient water in the pump sump and that suction pipe inlet is deep enough below water
	Impeller turns in wrong direction	Change rotation direction of impeller
	Pump does not run on speed	Increase speed
	Impeller eye too high above water level	Mount pump closer to water level
Pump does not deliver the correct amount of water and/or pressure	Impeller damaged or blocked	Dismantle pump and replace impeller
	Pump does not run on speed	Increase speed
	Foot valve or sieve in front of suction pipe inlet blocked	Clean foot valve or sieve
	Suction pipe inlet not deep enough under water	Ensure that there is sufficient water in pump sump and that suction pipe inlet is deep enough under water
	Unnoticeable leakages in pipe lines	Inspect pipe lines for leakages and repair
	Excessive wear of seals	Dismantle pump and repair
	Pump gasket leaks	Replace defective gasket
	Blockage in impeller or pump casing	Remove part of casing and clean
	Pump head underestimated	Test friction losses in pipes, bends, reducers and valves
	Obstruction in delivery pipe or incorrect diameter delivery pipe	Clean delivery pipe or install correct diameter delivery pipe
	Air leaks into suction line or stuffing box	Repair leakages or re-pack stuffing box
	Air accumulation at high points	Lower pump
	Impeller turns in wrong direction	Change direction of driver
Pump loses water after switch-on	NPSH not sufficient	Lower pump
	Air leaks into suction line or gasket casing	Repair leakages or re-pack gasket casing
	Suction pipe inlet not deep enough under water	Ensure that there is enough water in the pump sump and that suction pipe inlet is deep enough under water
	Liquid seal after stuffing box choked	Clean
Pump vibrates excessively/ excessive noise	Pump and motor incorrectly aligned	Realign pump and motor
	Impeller damaged or blocked	Dismantle pump, replace or clean impeller
	Electrical motor in imbalance on shaft	Have it checked / balanced
	Coupling damaged	Repair coupling
	Worn or loose bearings	Dismantle pump and replace bearings
	NPSH exceeded	Lower the pump
	Pump shaft bent	Dismantle pump and straighten or replace shaft
Pump uses excessive power	Serious leakage in delivery pipe	Repair leak
	Speed too high	Reduce speed
	Internal components of pump too tight	Dismantle pump and test clearances and adjust where necessary
	Impeller neck rings excessively worn	Dismantle pump and repair

Problem	Possible causes	Solution
	Pump bearings defective	Replace bearings and inspect lubrication
Bearings overheat	Pump and motor incorrectly aligned	Realign pump and motor
	Oil level too low or too high	Fill up or drain to correct level
	Wrong grade of oil	Drain oil, rinse and refill with correct grade of oil
	Bearings too tight	Ensure that bearings were correctly installed with the correct spacing. Replace if necessary
Varying pump delivery	Air leaks into suction line or stuffing box	Repair leakages or re-pack stuffing box
	Suction pipe inlet not deep enough under water	Ensure that there is enough water in the pump sump and that suction pipe inlet is deep enough under water
	Air or gas trapped in suction pipe	Switch off pump and de-aerate thoroughly

11 Power sources

11.1 General

The types of power sources being considered for irrigation mainly include electric motors and to a lesser extent internal combustion engines. The choice between these two main types of drive systems is usually based on economic considerations. The cost of electricity in proportion to that of fuel for an internal combustion engine is such that electricity is usually preferred, except where the cost of supplying electricity at a specific point is very high. Electric motors are consequently usually preferred to internal combustion engines and internal combustion engines are normally only used where three-phase power is unavailable, variable speed is required (which is very unlikely), or where the pump has to be portable. It is, however, also possible to make use of an electric motor for portable pumps, but then every pump station has to be provided with a three-phase power point.

Other sources of energy such as solar power may in future be applied for this purpose, but due to economic considerations and the fact that the best time to irrigate is at night, when the sun doesn't shine, and because the intensity of the sun is changeable, it is not yet being applied for irrigation purposes. Solar power is currently only being used for pumping water for domestic use and stock watering, where the delivery of the pump is very small and may also be variable.

Before a power source is selected for a pump, both the pump speed and the required power on the pump shaft must be known, as well as at the operating point and any variations thereupon in case anything unexpected should happen. With centrifugal pumps the required power will always rise if a pipe should burst because the pump will then be operating at a lower pump head and pumping a larger volume of water, which always goes hand in hand with an increase in power requirements, and it may damage the motor. With positive displacement pumps, just the opposite occurs, which is not so critical. It is also necessary to acquire some knowledge of the environmental conditions and what type of protection the installation will enjoy. Will it, for e.g., be housed in a pump house or installed out in the open.

11.2 Electric motors

Electric motors are now being put to almost any use and a wide variety of these motors are being manufactured.

11.2.1 Types of electric motors

Electric motors can be classified as shown in Figure 6.33 Mainly three-phase squirrel-cage motors are used for the driving of pumps, and in this chapter, we will therefore only be concentrating on this type of electric motor. The more expensive slip-ring motors need not be considered for irrigation.

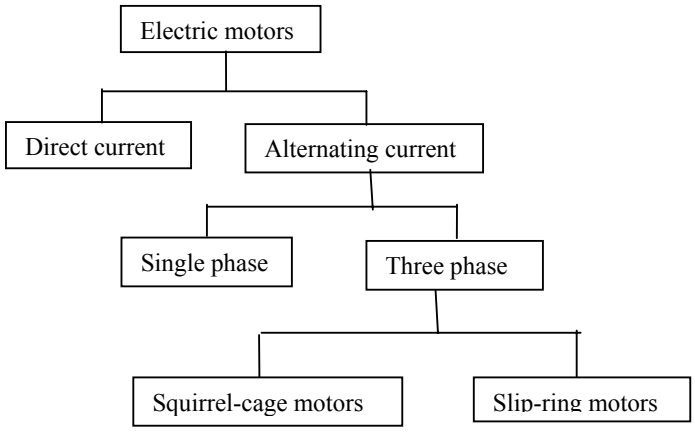

Figure 6.33: Simple classification of electric motors

11.2.2 Physical properties

The physical properties of electric motors exert a strong influence on their success as drivers.

11.2.2.1 Materials

An electric motor consists of copper wiring, insulation, laminated steel and a body manufactured from cast iron, aluminium or rolled steel. Cast iron bodies are robust and handle environmental conditions very well, but are relatively expensive to manufacture. The raw material of aluminium bodies is relatively inexpensive, but manufacturing the bodies from this material is expensive and besides being relatively soft, its ability to resist corrosion is questionable. However, the finished product looks good, performance compares well with that of cast iron, it is relatively light and its heat loss is excellent. Rolled steel bodies are relatively inexpensive and strong. They can also be manufactured so as to improve heat loss and provide a higher power rating.

11.2.2.2 Standard dimensions

Electric motors are also manufactured in such a way that they have certain standard dimensions. A frame size is usually referred to, which involves the difference between the centre point of the shaft and the bottom of the base. A standard series of frame sizes are available so the electric motor of one make can be replaced with another. A few standard dimensions are also linked to the frame size. These standard dimensions are indicated in Figure 6.34.

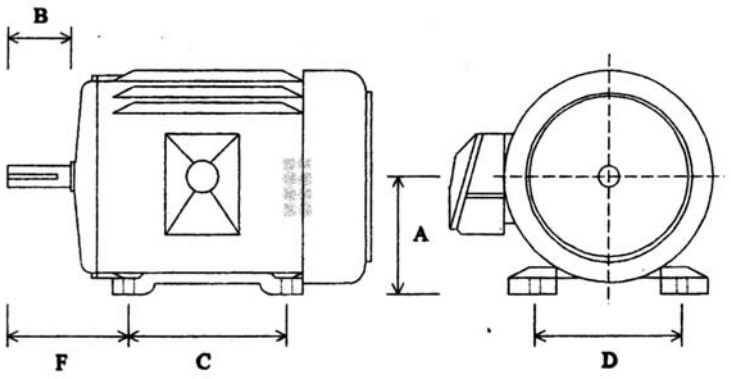

Figure 6.34: Standard dimensions of electric motors according to frame size

Frame sizes are specified according to dimension A in Figure 6.34, i.e. a frame size 132 means that dimension A for the motor concerned is 132 mm. The dimensions A, B,C, D and F will be the same for all electric motors of the same frame sizes.

11.2.2.3 Mounting

Electric motors can be mounted in one of the following ways:

- Base
- Flange
- Base/flange
- Body

A base mount is normally used for the powering of pumps. The so-called monoblock pumps, where the motor and pump are sold as an enclosed unit, makes use of flange mounting. No other mountings are used for irrigation purposes.

11.2.2.4 Cooling

Although heat loss also means a loss of energy, the motor has to be cooled to prevent it from overheating and thus being damaged. The IC code in accordance with SABS 948 (revised), IEC 34-6 and BS 4999/21 indicate the method of cooling. Of these, the TEFC motor (totally enclosed fan cooled) is the most well known. The most common methods are the following:

Table 6.4: Cooling methods

Code	Type of cooling	Common name
IC 01	External air is sucked in from outside the motor and blown out again	Drip proof
IC 01 41	Two separate air-flow paths. External air flows freely over external surface areas of motor's body. Internal air flows freely over internal surface area of motor.	Totally enclosed fan cooled
IC 00 41	No forced external cooling. Internal air flows over internal surface area of motor	Totally enclosed
IC 01 61	Two separate flow-paths by heat exchanger mounted on top of motor. External and internal air circulated through heat exchanger.	Closed air circuit air

To ensure that effective cooling of the motor takes place, the ventilation within the pump house is also very important.

11.2.2.5 Protection

Electric motors are manufactured to offer a certain standard of protection against live and moving parts, foreign objects and water. The IP code is used to indicate this protection. The code consists of IP, followed by two figures. The meaning of these two figures is indicated in Table 6.5. From this it can be seen that IP44 offers protection against contact with delicate tools and the entrance of solid objects larger than 1 mm, as well as against water splashing from any direction. IP 22, IP 44, IP 54 and IP 55 are the most common. Standard electric motors are manufactured for IP 44 protection, although certain manufacturers prefer IP 55.

Table 6.5: Protection of electric motors

Figure	Meaning of first figure Protection against live and moving parts as well as ingress of solid objects > 50 mm	Meaning of second figure Protection against harmful ingress of water
0	None	No protection
1	Accidental contact of live or moving parts and ingress of solid objects > 50 mm	Water drops that fall vertically
2	Contact with fingers and ingress of solid objects > 12 mm	Water drops falling 15° vertically
3		Spraying water 60° of the vertical
4	Contact with delicate tools and ingress of solid objects > 1 mm	Water splashing from any direction
5	Contact and protection against dust	Spraying water from any direction
6		Water on ships deck on rough sea
7		Submersing

11.3 Performance

11.3.1 Power rating

The power rating of an electric motor is its mechanical output capacity or rate of performance. Every electric motor has a certain maximum power which it is able to deliver. This is known as its power rating and it is thus a characteristic of a specific motor and that is why we refer to a 15 kW or a 22 kW motor. The series of power ratings of electric motors are standard. The standard power rating for three-phase electric motors, which will probably be used for the powering of irrigation pumps, are indicated in Table 6.6.

Table 6.6: Standard power ratings of some electric motors [kW]

0,75	3,0	11,0	30	75	160
1,1	4,0	15,0	37	90	185
1,5	5,5	18,5	45	110	200
2,2	7,5	22,0	55	132	220

The power rating of an electric motor is also influenced by the ambient temperature and the height above sea level. The power rating must be reduced according to Tables 6.7 and 6.8, where applicable. If the ambient temperature is above 40°C, the following reductions have to be applied:

Table 6.7: Reduction of allowable power rating according to ambient temperature above 40°C

Ambient temperature [°C]	**Allowable load [%]**
40	100
45	95
50	89
55	83
60	67
70	64

The higher the installation is above sea level, the thinner the air and the less effective the cooling that will take place. If an installation is more than 1 000 m above sea level, the following reductions in power rating must be applied if the ambient temperature is above the allowable ambient temperature.

Table 6.8: Reduction of power rating according to height above sea level

Height above sea level [m]	Allowable output power [%]	Allowable ambient temperature [°C]
0 to 1 000	100	40
1 000 to 2 000	92	32
2 000 to 3 000	83	24
3 000 to 4 000	74	16

It means that if the installation is 2 000 m above sea level, the maximum ambient temperature might be 32°C and if not, the power rating must be reduced to 92% of the original power rating. This reduction should, however, seldom be necessary under South African conditions.

11.3.2 Motor efficiency

The motor efficiency indicates the relationship between output power and input power and thus makes provision for energy losses that occur in the motor due to heat. The power required to drive the pump, i.e. the utilisable work that the motor performs, is the output power, while the power that has to be supplied to the motor is the input power.

Energy losses in an electric motor is thus equivalent to the input power less the output power. The motor efficiency varies according to the load of the motor. The nearer the electric motor runs to full power, the higher the motor efficiency will be. This, however, doesn't mean that the motor efficiency of a smaller motor for the same application will necessarily be better than that of a larger motor, because larger motors usually furnish us with a better motor efficiency than smaller motors.

11.3.3 Power factor

Power factor ($\cos \phi$) indicates that portion of the current in an alternating current circuit which the electric motor supplies in the form of energy. The remaining portion is watt-less. It is called reactive powering or watt-less current and is not used to perform any work. A kVA demand meter or ammeter will measure the full 100% current, i.e. the input kVA, but a watt meter will only register that portion of the current which is supplied in the form of energy, i.e. input kW. Power factor thus indicates the relationship between input kW and kVA demand.

Just as with motor efficiency, the labour factor also varies according to the load of the motor. The nearer the electric motor runs to full power, the larger the power factor will be. This, however, doesn't mean that the power factor of a smaller motor for the same application will inevitably be better than that of a larger motor. The power factor can be increased with the installation of static capacitors. The advantage of this is that a smaller kVA demand is required and that the reactive energy would also decrease if the power factor should increase. This may not hold any benefit for the smaller consumer, but it will benefit the larger consumer.

11.3.4 Rotor speed and direction

The rotor speed of electric motors is determined by the synchronous speed of the motor and the torque the motor has to produce. The synchronous speed of the motor is determined by the number of poles of the motor and the frequency of the electric supply current. The number of poles are 2, 4, 6, or 8 (in pairs of 2) with 2 and 4 being the most common for the driving of pumps.

The rotor speed itself is slightly lower than the synchronous speed, depending on the torque the electric motor has to produce. The difference between the synchronous speed and the rotor speed is called the slip speed. The synchronous speed of a four pole motor is thus 1 500 r/min and the rotor speed will thus vary to approximately 1 450 r/min, according to the load on the motor. In the USA the standard supply frequency is 60 Hz, i.e., there the synchronous speed of a four pole motor will be 1 800 r/min and the power rating of the motor will be approximately 15% higher for a two pole motor and 20% for a 4, 6, or 8 pole motor than in the RSA. A 60 Hz motor will initially run on the 50 Hz supply, but will overheat after a while and can thus not be used.

The standard direction of rotation of the shaft of an electric motor is clockwise if you look at the driving-shaft side of an electric motor. It concurs with the desired direction of rotation for centrifugal pumps. It is, however, possible to change the direction of rotation by changing the connection of the supply current. This must, however, be entrusted to a qualified electrician.

11.4 Selecting an electric motor

It is impossible to select equipment from any manufacturer without the technical information of that manufacturer. When selecting a suitable motor, the following have to be considered:

- **The speed against which the pump should run**
  If the pump speed is exactly 1 450 r/min or 2 900 r/min, the motor can be selected according to this. Pump curves are usually drawn for 2 900 r/min and 1 450 r/min. The reason for this is that it is compatible with the rotor speed of respectively a two pole and a four pole motor and in such a case, where the pump speed is equal to the rotor speed, direct coupling can be used. Where the pump speed is not equal to the rotor speed of the electric motor, belt and pulley coupling should be used and the motor that is selected, should have the rotor speed that is nearest to the pump speed so that the pulley ratio will not be excessively large.

- **The required power on the pump shaft**
  The selection of an electric motor in respect of power must be such that the motor is never overloaded. It is therefore necessary to find out what would happen if, for e.g., a pipe should burst, etc. The power of most centrifugal pumps would increase if the pump should pump against a smaller pump head. It would thus be necessary to either select a motor with a power rating that is large enough or to make provision by means of protection. Table 6.9 indicates the norms for minimum power rating of an electric motor for specific output power. The reduction in power rating, as set out in Table 6.7 and 6.8 must also be applied where necessary.

Table 6.9: Minimum power rating of electric motors for certain output powers

Output power [kW]	< 7,5 kW	7,5 kW to 37 kW	> 37 kW
Minimum power rating of motor	Output power + 20%	Output power + 15%	Output power + 10%

- **The $kVA_{available}$ at the power point**
  An electric motor should not be selected according to the $kVA_{available}$, but this is sometimes a limitation. The $kVA_{available}$ must, however, be sufficient to satisfy the kVA demand.

- **The ingress protection (IP) that should be provided for the motor**
  Standard electric motors are manufactured to provide IP 44 protection. This should be sufficient even though the motor might not be housed. If a cost saving can be effected by selecting a motor with a lower degree of protection, this might be considered where the environmental conditions allow.

11.5 Switch gear

Mainly two types of starting methods are used, namely
- Direct-on-line and
- Star-delta

Direct-on-line starters are normally used for smaller motors (< 2 kW) and star-delta where the starting current is excessively high and thus has to be reduced. Star-delta starters are usually used for irrigation purposes, but direct-on-line starters can be used at very small installations. The provider of electricity will also set his standards, because excessively high starting currents may impair the power supply to other consumers. It is important to entrust the connection of electrical equipment to a qualified electrician.

11.6 Protection

When it comes to protecting the motor, subjects like particularly overloading and lightning crop up. Overloading at the switch gear can be prevented by installing a safety switch that reacts to the current. As soon as the motor starts drawing excessive current, the switch will automatically cut out. This type of protection will also help to switch off most types of centrifugal pumps if a pipe should burst and the pump delivery increases dramatically. It is particularly important to use lightning conductors for submersible pumps if there is any danger of lightning striking, for e.g. where there is a windmill near the installation which might attract lightning. There are currently various products on the market offering protection against a whole series of undesirable events and the catalogues of manufacturers should thus be consulted.

11.7 Supply cables

Cable designs are usually executed to conform to SABS 0142-1981, Regulation 4.3.4. This regulation dictates that the maximum voltage drop under full-load conditions may not exceed 5%. It boils down to 19 V between phase and phase and 11 V between phase and neutral if the voltage is 380 V. The cable size must, however, be based on the voltage drop [ΔV] of 5% maximum between phase and neutral, i.e. 5% of 220 V = 11 V.

The full-load current of a motor is the maximum current that an electric motor can draw before overheating. For the designing of cable sizes it is better to use this current, except in cases where the power rating of the electric motor is much larger than the required power.

Table 6.10: Maximum cable length [m]

Power rating of motor		Full-load current	Cable size [mm^2]										
[kW]	[HP]	[A]	1,5	2,5	4	6	10	16	25	35	50	70	95
2,2	3	5,3	143	243	387	584	964	2 535	2 439				
3,0	4	7	108	184	293	442	730	1 162	1 847				
4,0	5,5	8,9	85	145	230	347	574	914	1 452	2 058			
5,5	7,5	12,6	60	102	163	245	405	646	1 026	1 453	1 960		
7,5	10	15,8	47	81	130	195	323	515	818	1 159	1 563	2 073	
11	15	23		56	89	134	222	353	562	796	1 073	1 426	1 803
15	20	31			66	99	164	262	417	590	796	1 058	1 337
18,5	25	38				81	134	214	340	482	649	863	1 091
22	30	45					113	180	287	407	545	729	921
30	40	61						133	211	300	404	537	679
37	50	76						107	170	241	324	431	545
45	60	91							142	201	271	360	455
55	75	108							119	169	228	303	333
75	100	149									165	220	278
90	120	176										186	235

Table 6.10 indicates the maximum cable length for 380 V voltage for different cable sizes that can be used for an electric motor of a certain size. Table 6.10 can also be used for longer cables to determine the most suitable cable size. It is also based on a voltage drop of 5% between phase and neutral.

If the cable size is too small, the voltage [V] decreases and this causes the electric motor to draw a higher current. The motor may thus overheat sooner than expected and the energy loss will also increase. It is thus very important not to use cables that are too small.

12 Internal combustion engines

Internal combustion engines are also commonly used for the driving of pumps, especially where electricity is unavailable.

12.1 Types of internal combustion engines

There are mainly two types of internal combustion engines, namely

- Petrol-driven engines, and
- Diesel engines

Petrol-driven engines are cheaper and lighter, but with diesel engines the fuel consumption is better, they are able to operate for longer hours and they have a longer life-span. In practice, petrol-driven engines are only considered for smaller portable pumps, while diesel engines occupy the rest of the market. The rest of the discussion on internal combustion engines will thus be devoted to diesel engines.

Diesel engines are also sometimes classified according to type of cooling. The two main types of cooling are water and air cooling.

12.2 Performance of diesel engines

A typical performance curve for a diesel engine appears in Figure 6.36.

On this performance curve are indicated the torque [Nm] that the diesel engine will generate, the power ratings and the fuel consumption. Three curves usually indicate the power ratings. In Figure 6.35 they are shown as curves A, B, and C. Curve A indicates the maximum gross power rating of the engine. This, however, is only for information and may not be used to make a selection. Curve B indicates the uninterrupted power rating, i.e. the power the engine will be delivering over short periods. Curve C indicates the continuous power rating, i.e. the power the engine will be delivering when it is operating continuously. For the powering of pumps, curve C will thus have to be used. The power rating of diesel engines is also influenced by height above sea level, air temperature and humidity. The higher the site is above sea level, the higher the temperature and the lower the humidity, the larger the reduction that will have to be applied.

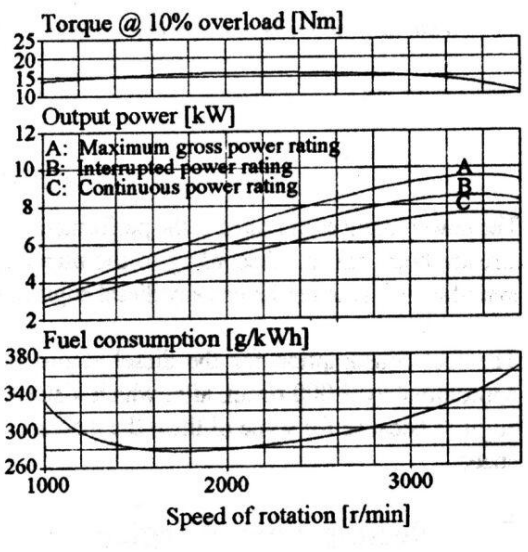

Figure 6.35: Typical performance curve of a diesel engine

The power rating as indicated in the performance curve is also only applicable on a diesel engine that has already been run in. According to the manufacturers, this takes approximately 50 hours. Ask the manufacturer whether he has any diesel engines that have been run in in the factory. The fuel consumption for the diesel engine in Figure 6.35 shows a decrease from 1 000 r/min to approximately 2 000 r/min, after which it starts climbing again. However, this is not true for all diesel engines because for some of them the increase in fuel consumption is commensurate with the increase in speed.

12.3 Selecting a diesel engine

When a diesel engine is selected, the following points must be borne in mind:

12.3.1 General

- Aligned engines require less maintenance and less spare parts than V engines with the same power rating.
- Water cooling provides more uniform temperature distribution at parts subject to thermal loads. However, air-cooled engines reach their optimum temperature sooner, which again means less wear and tear.
- Turbo boosting should be considered during the planning stage.
- It should be possible to service engines without needing special tools.

12.3.2 Required performance

- The engine should be able to satisfy the power rating demand. The speed at which this demand is satisfied, is not so important because the required pump speed can be obtained with a suitable coupling. If indirect coupling is preferred, the engine should, however, run at the desired pump speed.
- The engine with the lowest total cost, i.e. purchase price plus running costs such as fuel and maintenance, should receive preference. Performance is at its best at peak torque.

13 Coupling

The type of coupling, direct or belt and pulley, is mainly determined by the speed of the driver vs. the speed at which the pump must run. If it is equal, direct coupling will probably be the proper method to follow. If not, belt and pulley coupling should be used.

13.1 Direct coupling

A number of types of direct couplings can be used, of which flexible belt coupling is the most commonly used. Manufacturers of direct couplings usually indicate in their catalogues the methods according to which the correct couplings should be selected.

11.1.1 Power ratings

Manufacturers of direct couplers indicate the power ratings of a series of couplers in their catalogues.

11.1.2 Coupling

Ensure that the coupling fits onto both shafts and therefore get the dimensions from the supplier and compare them. These couplings can also to a certain degree compensate for misalignment. Maximum values for this also appear in the catalogues. However, this is no reason to neglect alignment. Direct couplings can be regarded as being 100% efficient.

13.2 Belt and pulley coupling

The designing of belt and pulley coupling consists of three steps, namely the determination of:

- the type of belt,
- the exact dimensions of the pulleys, distance between pulleys and belt lengths, and
- the number of belts to be used.

13.2.1 Determination of the type of belt

The type of belt is mainly influenced by the design power and the speed of the faster shaft.

The selection of a type of belt must then be done according to the speed of the faster shaft and the design power. Please note that the type of belt cannot be selected without the manufacturer's catalogue.

If two types of belts could possibly be suitable, select the belt of which the point of intersection of the design power and the speed of the faster shaft lies nearest to the centre of the two lines.

13.2.2 Determination of pulley sizes, distance between centre points and belt length

The pulley sizes are mainly determined by the desired speed ratio, but sometimes belt and pump manufacturers also lay down certain specifications. These specifications appear in the catalogues of the manufacturers concerned.

14 Energy costs

Energy costs play a very important role in the economic viability of a pump installation. In many areas, ESKOM is the only supplier of electricity, while diesel engines are normally used where electricity is unavailable.

14.1 ESKOM tariff structures

For rural users ESKOM has tree tariff options for the supply of electricity. These are NIGHTSAVE Rural, RURAFLEX, and LANDRATE. A brief description of each tariff is given in Table 6.11 below.

Table 6.11: Description of ESKOM tariff options for rural users

Tariff plan	Description
NIGHTSAVE Rural	This is for customers with a notified monthly demand of at least 25 kW/kVA. With a supply voltage ≤ 22 kV, who can move all or part of their demand to off-peak periods (i.e. 22:00 – 06:00 weekdays and the entire Saturday and Sunday).
RURAFLEX	This tariff is applicable to 3-phase customers with a supply voltage of 400 V up to 22 kV and who can shift their load to defined time periods.
LANDRATE	This is for rural customers with a notified monthly demand of 100 kVA or less. LANDRATE is subdivided into 5 categories.

The costs and surcharges for each of the three tariff structures will be described in the next few sections. All surcharges, tariffs and costs in Section 5.1.1 – 5.1.3 are based on July to December 2002 tariffs. All tariffs indicated include VAT. A brief description of the costs and an example of the current rates will be given.

14.1.1 NIGHTSAVE Rural

- **Connection fee**

A connection fee is charged for each of the three tariff structures. The amount charged is determined by the size of the supply and well as the payment method (conventional or prepayment). The charge for a 5 kVA single phase supply is R 1 300,00 and for a 500 kVA supply it is R 15 000,00 (including VAT).

- **Capital costs**

For a new connection, ESKOM may charge a monthly and/or up-front payment to recover capital costs that are not covered by the tariff. Where applicable, the monthly charge for all existing connections will be subject to a rebate at R 2,00 per kVA or kW of chargeable demand.

- **Service charge**

This a fix charge payable every month, whether electricity is consumed or not, based on the utilised capacity and charged per account. This fee is a contribution towards ESKOM's customer service costs. This fee ranges from R 135,81 for a supply ≤ 100 kVA or R 1 448,11 for supplies > 1 MVA.

- **Administration charge**

This is a monthly charge that is based on the utilised capacity of each point of delivery and is charged whether electricity is consumed or not. This charge covers ESKOM's fixed costs such as meter reading and billing. The charge ranges from R 103,32 for a supply ≤ 100 kVA to R 925,06 for supplies > 1 MVA.

- **Network charge**

This is a fixed charge payable each month, whether electricity is consumed or not, to cover ESKOM's fixed network capital costs and it is based on the utilised capacity where applicable. This fee is R 2,30/kVA or kW.

- **Demand charge**

This charge is payable for each kVA of the maximum chargeable demand supplied during the month. This fee varies for the high- and low-demand seasons in the year.

High-demand season (June-August)	Low-demand season (September-May)
R 32,58 /kVA	R20,28 / kVA
R 38,34 / kW	R23,86 / kW

The charge is only applicable to the accumulated kVA or kW consumed during peak periods. Where the charge is per kW, the power factor may not be less than 0,85 lagging and it may not lead under any circumstances.

- **Active energy charge**

This is the charge per kWh for electricity actually consumed. This rate is differentiated for high- and low-demand times of the year.

High-demand season (June-August)	Low-demand season (September-May)
13.46c / kWh	9,82c / kWh

- **Voltage surcharge**

A surcharge is levied to account for the higher costs of supplying low voltages. This is charged at a fixed percent of demand, active energy and network charges.

Supply voltage	Surcharge
> 22 kV	7,63%
≥ 500 V and ≤ 22 kV	10,07%
< 500 V	17,30%

- **Transmission surcharge**

This is calculated as a fixed percentage of demand, active energy and network charges after the voltage surcharge has been levied. This percentage depends on the distance from Johannesburg and is shown in Table 6.12.

Table 6.12: Transmission surcharge levied depending on the distance from Johannesburg to the point of supply

Distance from transformer to Johannesburg [km]	Transmission surcharge [%]
0 - 300	0
301 - 600	1
601 - 900	2
> 900	3

- **Time periods**

The peak time periods are weekdays from 06:00 until 22:00 and off-peak the rest of the week.

14.1.2 RURAFLEX

- **Connection fee**

A connection fee is charged for each of the three tariff structures. The amount charged is determined by the size of the supply and well as the payment method (conventional or prepayment) The charge for a 5 kVA single phase supply is R 1 300,00 and for a 500 kVA supply it is R 15 000,00 (including VAT).

- **Capital costs**

For a new connection, ESKOM may charge a monthly and/or up-front payment to recover capital costs that are not covered by the tariff. Where applicable, the monthly charge for all existing connections will be subject to a rebate at 1,81c per kWh of all active energy consumed during peak periods.

- **Service charge**

This is a fixed charge payable every month, whether electricity is consumed or not, based on the utilised capacity and charge per account. This fee is a contribution towards ESKOM's customer service costs. This fee ranges from R 135,81 for a supply ≤ 100 kVA to R 1 448,11 for supplies > 1 MVA.

- **Administration charge**

This is a monthly charge that is based on the utilised capacity of each point of delivery and is charged whether electricity is consumed or not. This charge covers ESKOM's fixed costs such as meter reading and billing. The charge ranges from R 95,63 for a supply ≤ 100 kVA or R 921,48 for supplies > 1 MVA.

- **Network charge**

This is a fixed charge payable each month, whether electricity is consumed or not, to cover ESKOM's fixed network capital costs and it is based on the utilised capacity where applicable. This fee is R 2,06/kVA.

- **Active energy charge**

This is the charge per kWh for electricity actually consumed. This rate is differentiated for high- and low-demand times of the year.

Time period	High-demand season (June-August)	Low-demand season (September-May)
Peak	71,47 c/kWh	20,00 c/kWh
Standard	18,71 c/kWh	12,31 c/kWh
Off-peak	10,01 c/kWh	8,64 c/kWh

- **Reactive energy charge**

Reactive energy involves that portion of the current that the electric motor consumes but does not supply in the form of energy. The power factor indicates that portion of the current which is supplied in the form of energy. A low power factor will thus be the cause of high reactive energy. For rural areas, this only has a bearing on the Ruraflex tariff and only reactive energy that exceeds 30% of the active energy consumption is paid for. The reactive energy is expressed in kiloVolt-Ampére reactive-hour (kVArh) and can be calculated with the following equation:

$$E_r = E_a \tan\phi \qquad (6.2)$$

where E_r = reactive energy consumption [kVArh]
E_a = active energy consumption [kWh]
$\tan\phi$ = $\tan(\cos^{-1}(\cos\phi))$

There is no reactive energy charge for users that have a power factor of 0,96 or better.

- **Voltage surcharge**

A surcharge is levied to account for the higher costs of supplying low voltages. This is charged at a fixed percent of demand, active energy and network charges.

- **Transmission surcharge**

This is calculated as a fixed percentage of demand, active energy and network charges after the voltage surcharge has been levied. This percentage depends on the distance from Johannesburg and is shown in Table 6.12.

- **Time periods**

The peak time periods are weekdays from 06:00 until 22:00 and off-peak the rest of the week.

Table 6.13: Time period for the RURAFLEX tariff option

Day	Peak	Standard	Off-peak
Weekdays	07:00 to 10:00 18:00 to 20:00	06:00 to 07:00 10:00 to 18:00 20:00 to 22:00	22:00 to 06:00
Saturday	-	07:00 to 12:00 18:00 to 20:00	12:00 to 18:00 20:00 to 07:00
Sunday	-	-	Whole day

14.1.3 LANDRATE

This range of tariffs is for rural supplies with a notified monthly demand of 100 kVA or less. It is usually supplied from an 11 or 22 kV network at a nominal voltage lower than 500 V.

- **Standard supply sizes**

  There are five LANDRATE packages available:

Table 6.14: Landrate options

Option	Number of phases	Supply point
LANDRATE 1	Single-phase Dual-phase Three-phase	16 kVA (80 A) 32 kVA (80 A) 25 kVA (40 A)
LANDRATE 2	Dual-phase Three-phase	64 kVA (160 A) 50 kVA (80 A)
LANDRATE 3	Dual-phase Three-phase	100 kVA (225 A) 100 kVA (160 A)
LANDRATE 4	Single-phase	16 kVA (80 A)
LANDRATE Dx	Single-phase	10 A (limited supply capacity)

LANDRATE 1, 2 and 3 – these are suitable for supplies that use consistently more than 1 000 kWh per month. The basic and network charge is payable for each point of delivery and the network charge is graded according to the standard supply sizes applicable to each tariff.

LANDRATE 4 – is suitable for single-phase supplies where consistently less than 1 000 kWh are being used each month. The network charge is payable for each point of delivery.

LANDRATE Dx – this tariff is applicable to very low usage single supplies where the electricity usage is low enough to not warrant metering for billing purposes. Only the basic charge is payable each month for each point of delivery. This tariff is typically suitable for small telecommunication installations.

- **Prepayment supplies**

Points of delivery with prepaid meters are available for LANDRATER 1, 2 and 4. LANDRATE 1 and 4 have a single-phase supply with a maximum amperage of 60 A. LANDRATE 2 has a three-phase supply with a maximum amperage of 80 A.

- **Connection fee**

A connection fee is charge for each of the three tariff structures. The amount charged is determined by the size of the supply and well as the payment method (conventional or prepayment).

- **Capital costs**

For a new connection, ESKOM may charge a monthly and/or up-front payment to recover capital costs that are not covered by the tariff.

- **Charges**

The charges are broken down into basic, network and energy charges. These charges (subject to increases) are as follows:

Table 6.15: Comparative charges for Landrate options (subject to increases)

Tariff	Basic charge (R/month)	Network charge (R/month)	Energy charge (c/kWh)
LANDRATE 1	159,43	148,20	21,81
LANDRATE 2	159,43	228,00	21,81
LANDRATE 3	159,43	364,80	21,81
LANDRATE 4	N/A	107,19	42,10
LANDRATE Dx	308,72	N/A	N/A

14.1.4 Determination of electricity costs

For the determination of electricity costs by the customer support service, the following should be known:

- The size of the motor of every appliance that is being supplied from a specific power point and the input power and power factor of each of these.
- For how may hours per month pumping will take place. If more than one appliance is being supplied with electricity from a specific power point, the consumption of each appliance has to be estimated.

Example 6.1:

Maize and wheat are being cultivated under a 40 ha centre pivot in the Van Der Kloof Dam area. The centre pivot is serviced by a centrifugal pump with a pump delivery of 245 m^3/h, which requires 38,5 kW on the pump shaft and is being driven by a 45 kW four pole motor. The maize is planted on 15 December and the wheat on 15 June and the crops are irrigated according to the irrigation demands set out in "Estimated Irrigation Requirements for Crops in South Africa, Part 2". The system efficiency can be accepted as 85%. ESKOM supplies the electricity (three-phase) with a 100 kVA power point. The transformer is approximately 550 km from Johannesburg and ESKOM has built a 700 m power line. (Accept the power consumption for driving the centre pivot as being 2,5 kWh/mm net application and the kVA demand as 6,5 kVA.)

Solution:

- *Determine the input power of the electric motor:*
  Motor efficiency according to the manufacturer's catalogue is 91%.

$$P_i = \frac{100 \times P_u}{\eta}$$

$$= \frac{100 \times 38,5}{91}$$

$$= 42,31 \ kW$$

- *Determine the power factor and kVA demand:*
  Power factor from the manufacturer's catalogue: 0,82

$$kVA = \frac{P_i}{\cos \phi}$$

$$= \frac{42,31}{0,82}$$

$$= 51,60 \ kVA$$

Add 6,5 kVA for powering the centre pivot:

$$kVA = 51,60 + 6,5$$

$$= 58,10 \ kVA$$

- *Determine the monthly energy requirement:*

  First obtain the net irrigation requirement using the SAPWAT (or elsewhere, if applicable). The next step is to determine the gross irrigation requirement:

$$GIR = \frac{100 \ NIR}{\eta_s} \qquad (6.3)$$

where GIR = *gross irrigation requirement [mm/period]*
NIR = *net irrigation requirement [mm/period]*
η_s = *system efficiency*

ESKOM accounts are presented on a monthly basis so monthly periods are employed.

The volume of water to be pumped can then be determined as follows:

$$V = 10 \; A \; GIR \qquad (6.4)$$

where V = *volume of water to be pumped [m^3]*
A = *area to be irrigated [ha]*
GIR = *gross irrigation requirement [mm/period]*

$$t = \frac{V}{Q} \qquad (6.5)$$

Thereafter the pumping hours are calculated as follows:

where t = *pumping hours [h]*
V = *volume of water to be pumped [m^3]*
Q = *pumping rate [m^3/h]*

The total energy requirement per period can then be determined as follows: (Optional)

$$E = t \; P_i \qquad (6.6)$$

where E = *total energy requirement per period [kWh]*
t = *pumping hours [h]*
P_i = *input power [kW]*

Thus information for maize:

Month	***Dec***	***Jan***	***Feb***	***Mar***	***Apr***
Nett irrigation requirements mm/month	*103*	*312*	*297*	*198*	*27*
Gross irrigation requirements mm month	*121*	*367*	*349*	*233*	*32*
Volume irrigation [m^3/month]	*48 471*	*146 824*	*139*	*93 176*	*12 706*
Pumping hours [hour/month]	*198*	*599*	*570*	*380*	*52*
Energy requirement of pump [kWh/month]	*8 371*	*25 356*	*24 137*	*16 091*	*2 194*
Energy requirement of pivot [kWh/month]	*258*	*780*	*743*	*495*	*68*
Total energy consumption [kWh/month]	*8 628*	*26 136*	*24 879*	*16 586*	*2 262*

Thus, information for wheat:

Month	***Jun***	***Jul***	***Aug***	***Sep***	***Oct***	***Nov***
Nett irrigation requirements (mm/month)	*22*	*55*	*161*	*273*	*258*	*60*
Gross irrigation requirements (mm/month)	*26*	*65*	*189*	*321*	*304*	*71*
Volume irrigation [m^3/month]	*10 353*	*25 882*	*75 765*	*128*	*121*	*28 235*
Pumping hours [hour/month]	*42*	*106*	*309*	*524*	*496*	*115*
Energy req. of pump [kWh/month]	*1 788*	*4 470*	*13 084*	*22 186*	*20 967*	*4 876*
Energy req. of pivot [kWh/month]	*55*	*138*	*403*	*683*	*645*	*150*
Total energy cons. [kWh/month]	*1 843*	*4 608*	*13 487*	*22 869*	*21 612*	*5 026*

The following information can thus be given to ESKOM:

Size of electric motor: 45,00 kW
Input power: 42,31 kW
Power factor: 0,82

Monthly pumping hours and energy requirements:

Month	***Pump hours [h]***	***Energy usage [kWh]***	***Month***	***Pump hours [h]***	***Energy usage [kWh]***	***Month***	***Pump hours [h]***	***Energy usage [kWh]***
Dec	*198*	*8 628*	*Apr*	*52*	*2 262*	*Aug*	*309*	*13 487*
Jan	*599*	*26 136*	*May*	*0*	*0*	*Sep*	*524*	*22 869*
Feb	*570*	*24 879*	*Jun*	*42*	*1 843*	*Oct*	*496*	*21 612*
Mar	*380*	*16 586*	*Jul*	*106*	*4 608*	*Nov*	*115*	*5 026*

This information will enable ESKOM to determine the best tariff for the specific point.

For illustration of the effect of the different tariffs on the energy cost, the energy costs for each tariff was determined by ESKOM's tariff for July to December 2002 for the above example. However, please note that many variables can influence these costs and these figures should therefore not be regarded as the general tendency. For this example, the LANDRATE 3, NIGHTSAVE and RURAFLEX tariff options are applicable.

Furthermore, RURAFLEX and NIGHTSAVE tariffs are sensitive to the exact time that electricity is consumed.

Two different monthly costs were calculated for each of three tariffs, namely for:

- *A normal pattern of consumption with the supposition that irrigation will start at 07:00 on Tuesday morning and continue flat out until the weekly irrigation demand has been satisfied, irrespective of time and consumption.*

- *An optimum pattern of consumption where full use is made of the cheaper periods before irrigating during the more expensive periods.*

No optimisation is possible for the LANDRATE 3 tariff option as the same unit costs is charged throughout the day.

For the NIGHTSAVE tariff, no saving is realised if electricity is consumed during the peak periods of the day. The monthly fixed costs are the same for both scenarios. By shifting the consumption of electricity to off-peak times, considerable savings can be realised by reducing the demand charge.

For the RURAFLEX tariff an estimated for the reactive energy cost must be made, as this is determined on a monthly basis from meter readings. An amount of R120,00 pm was assumed for this cost. The breakdown of the number of kWh in each rate category for the two scenarios shown in the table below.

Month	***RURAFLEX No optimisation [KWh / month]***			***RURAFLEX Optimised [KWh / month]***		
	Peak	***Standard***	***Off-peak***	***Peak***	***Standard***	***Off-peak***
December	*1 803*	*4 009*	*2 789*	*8 628*	*0*	*0*
January	*4 014*	*9 381*	*12 741*	*14 853*	*11 301*	*0*
February	*3 429*	*8 729*	*12 658*	*14 840*	*10 039*	*0*
March	*3 492*	*7 333*	*5 761*	*14 840*	*1 746*	*0*
April	*696*	*1 566*	*0*	*2 262*	*0*	*0*
May	*0*	*0*	*0*	*0*	*0*	*0*
June	*527*	*1 316*	*0*	*1 843*	*0*	*0*
July	*1 304*	*1 913*	*1 391*	*4 608*	*0*	*0*
August	*3 143*	*6 154*	*4 190*	*13 487*	*0*	*0*
September	*3 491*	*8 729*	*10 649*	*14 839*	*8 030*	*0*
October	*3 486*	*8 715*	*9 412*	*14 815*	*6 797*	*0*
November	*1 399*	*2 229*	*1 399*	*5 026*	*0*	*0*

The total monthly costs for the LANDRATE 3, NIGHTSAVE and RURAFLEX tariff options are shown in the Table below. For this example the benefit of timing the use of electricity is evident. In this example, the optimised RURAFLEX option will have the lowest annual costs. However, there are other factors that may influence the choice of tariff structure. For instance, in some regions centre pivots cannot be run at night due to the possibility of water freezing and causing the centre pivot to collapse. Also, certain crops cannot be irrigated at night.

Month	***Tariff (R / month)***				
	Landrate 3	***Nightsave Rural***		***Ruraflex***	
		No optimised	***Optimised***	***No optimised***	***Optimised***
December	*1 882*	*2 591*	*1 310*	*1 773*	*1 387*
January	*5 700*	*4 460*	*4 460*	*3 901*	*3 482*
February	*5 426*	*4 326*	*4 326*	*3 693*	*3 314*
March	*3 617*	*3 441*	*2 160*	*2 858*	*2 204*
April	*493*	*1 911*	*631*	*937*	*789*
May	*0*	*1 670*	*389*	*455*	*455*
June	*402*	*2 644*	*586*	*867*	*750*
July	*1 005*	*2 939*	*881*	*1 247*	*1 009*
August	*2 942*	*3 887*	*1 829*	*2 477*	*1 843*
September	*4 988*	*4 111*	*4 111*	*3 504*	*3 045*
October	*4 714*	*3 977*	*3 977*	*3 385*	*2 878*
November	*1 096*	*2 207*	*926*	*1 310*	*1 049*
TOTAL:	*32 265*	*38 163*	*22 585*	*26 407*	*22 205*
Optimisation savings		*15 578*		*4 202*	

The cost per kWh is thus (at 2002 tariff with VAT included):
LANDRATE 3: *R 0,22/kWh*
NIGHTSAVE Rural optimised: *R 0,18/kWh*
RURAFLEX optimised: *R 0,15/kWh*
NIGHTSAVE Rural no optimisation: *R 0,26/kWh*
RURAFLEX no optimisation: *R 0,17/kWh*

Please note that these comparative costs were done for a specific situation and are not necessarily a general tendency.

14.2 Diesel costs

Determining diesel costs is much simpler than determining the cost of electricity supplied by ESKOM, i.e. if the fuel consumption is known.

Example 6.2:
Determine the diesel cost for supplying water to the maize crop under the centre pivot mentioned in Section 14.1.4 if the diesel engine's fuel consumption is 240 g/kWh. (Accept pumping hours similar to those above, the power as 38,5 kW, the density of the diesel as 810 g/ℓ and the cost of diesel as R3,56/ℓ).

Solution:

Row	***Month***	***Dec***	***Jan***	***Feb***	***Mar***	***Apr***
1	*Pumping hours (hour/month)*	*198*	*599*	*570*	*380*	*52*
2	*Energy requirement (kWh/month)*	*7 623*	*23 062*	*21 945*	*14 630*	*2 002*
3	*Diesel consumption (kg/month)*	*1 829*	*5 535*	*5 267*	*3 511*	*480*
4	*Diesel consumption (ℓ/month)*	*2 259*	*6 833*	*6 502*	*4 335*	*593*
5	*Diesel cost (R/month)*	*8 042*	*24 325*	*23 147*	*15 433*	*2 111*

Row 1: Pumping hours as calculated in example 17.9
Row 2: Energy requirement [kWh/mo.] = row 1 × 38,5 kW
Row 3: Diesel consumption [kg/mo.] = Row 2 × 0,240 kg/kWh
Row 4: Diesel consumption [ℓ/mo.] = Row 3 /0,810 kg/ℓ
Row 5: Diesel cost [R/mo.] = Row 4 × R3,56 ℓ

Thus, Total diesel cost per season: R73 058
Total diesel cost per ha: R 1 826
Average cost per kWh: R 1,05 (NB based on 2002 tariffs, VAT included).

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